Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

CRA

Includes description of a project on Hydro - Sed. modeling
description of soil water status + movement project
" of infiltration measurement project

COOPERATIVE STUDY ON STREAMBANK STABILITY

USDA Sedimentation Laboratory

and

Vicksburg District Corps of Engineers

U.S. Sed. Lab - Oxford, MS
Streambank Stabilization

FY 1977-FY 1980

Oxford, Mississippi

An Experimental Study of Streambank Stability

Problems of sediment accumulation in river channels and of bank instability initiated Public Law 93-251, a project designed to 1 demonstrate the effectiveness of alternative bank revetment and stabilization practices, 2 identify soil stability problems and causes of erosion and make recommendations on means for the prevention and correction of streambank erosion. In order to accomplish this, a series of stabilization structures will be installed by the Corps of Engineers, and a data collection and evaluation program initiated by ARS to determine the influence of the structures on local hydraulic conditions, and the influence of upland management practices on their performance.

Yocona River
Enid Reservoir ?

One bluff-line tributary between Sardis and Grenada Reservoirs in the Yazoo Basin will be selected for detailed instrumentation and observation of channel stabilization problems. A maximum of 10 to 12 stations are proposed for the study watershed. Revetment methods and grade control structures on additional tributaries will be monitored and their performance evaluated using at least 6 gaging stations.

Basically, the proposed project will characterize (1) the channel and flow conditions in the vicinity of major channel stabilization structures, (2) the geomorphological features of the study area, and (3) watershed features including water and sediment source areas as a basis for assessing their influence on channel stability. It is proposed to conduct four years of extensive field and laboratory studies of selected measurable parameters. The channel and flow conditions will be characterized by stream discharge, sediment load, ground-water conditions and channel shape. The geomorphological features will be characterized by studying the channel morphology, watershed topography and valley stratigraphy. The watershed features will be characterized by an extensive data collection network of major climatic, hydrologic, soil, land use and sediment parameters. Modeling of channel stability will be supported by laboratory studies of flow resistance, turbulent entrainment, and sediment transport.

It was the intent of the USDA Sedimentation Laboratory, when setting up the series of watersheds, to have all the data needed for testing the various sediment and water quality models that are available and to make the data available to anyone in ARS or the Corps of Engineers. This we intend to do. Because of the Public Law, under which the watersheds will be instrumented, does not request water quality data, collection of these data are not described. However in the near future, we anticipate interest on the part of the Forest Service, Soil Conservation Service, and the Environmental Protection Administration in these type data. Thus, ultimately we expect to collect data on various water quality parameters.

The following documents describe both the present project with the U. S. Army Corps of Engineers and the supporting USDA Sedimentation Laboratory research outlines in more detail.

The specific objectives of the study are:

1. Determine the influence of grade control structures on channel stability.

2. Monitor and evaluate the performance of selected types of channel stabilization methods installed in the study area.

3. To the extent possible evaluate the effects of geology, geomorphology, soils, land use and climate on runoff and sediment production from representative sites in major source areas within the study watershed.

4. Estimate the water and sediment production from large mixed land use watersheds and the integrated effects of these on channel stability.

5. Evaluate the relation between valley stratigraphy and channel morphology and their combined effects on channel stability.

In support of this proposal, the Laboratory has prepared 9 Research Outlines under four projects. These are as follows:

Channel stability as influenced by watershed processes, valley stratigraphy, and grade control

1. Stream Bank Stability as Influenced by Upland Watershed Processes

2. Channel Stability as Controlled by Valley Stratigraphy

3. An Experimental Model Study of Low-Drop Grade Control Structures

Modeling watershed processes

4. Computational Modeling of Water and Sediment Yield from Agricultural Watersheds as Related to Stream Stability

Entrainment, transport, and energy dissipation in alluvial channels

5. Entrainment of Streambed Particles by Turbulent Surface Flows

6. Large-Scale Model Study of the Transport of Bed Material from a Natural Stream

7. Alluvial Channel Flow Resistance Under Transient Flow Conditions

Sediment production, soil water state, and runoff for land contributing to channel systems

8. Runoff, Erosion, Infiltration, and Sediment Characteristics of Selected Soils and Land Uses

9. Soil Water State for Study Watersheds

Specific objective 1 will be addressed by outline 3, objective 2 by outline 1, objective 3 by outline 1, objective 4 by outlines 1, 4, 5, 6, 7, 8, and 9, and objective 5 by outline 2.

4

March 11, 1977

Colonel Gerald E. Galloway
Department of army, Vicksburg District, CE
P. O. Box 60
Vicksburg, MS 39180

Dear Colonel Galloway:

Enclosed is the ARS proposal to undertake a project entitled "An Experimental Study of Streambank Stability". The proposal is basically the same as the draft proposal forwarded to you the First of February. However, we have reduced the scope of the studies considerably in order to stay within a prescribed monetary constraint. The total cost of the proposal is now about 2.75 million dollars. The reduction in scope of the study will make it much more difficult to extrapolate the results of the study to other areas. The ability to extrapolate research results to other areas is contingent upon a data base for verification. It is this component of the initial proposal that we had to curtail the most; this was the most expensive part of the proposal. However, we feel that the revised proposal we have prepared will have more potential for extrapolation than any other we could have prepared.

In the initial proposal we expected to establish 2 or more completely monitored nested watersheds to enable us to evaluate the variety of soils, morphologies and land uses and structural measures in the bluff line tributaries of the Yazoo River Basin. In this proposal we have had to limit this to one nested set of watersheds with a possibility of one or two stations on other bluff line watersheds, and a significantly reduced effort in the watershed and laboratory support projects. This means that we cannot investigate the variety of conditions that we would like. However, I feel that the model that we will develop will still enable us to do a better job of predicting the effects of changes in land use on the stability of the ungaged watersheds than if no funds were expended for indepth studies, and all funds had been diverted to watershed monitoring.

The proposal is supported by 9 specific research projects (reduced from the 10 previously prepared) prepared for inhouse support. We have not had time to retype and copy them; however, they are available here if any one would like to study them. As with the previous proposal, we are sending it to Dr. C. D. Ranney, the Alabama-North Mississippi Area Director for ARS, Dr. A. W. Cooper, the Southern Region Deputy Administrator for ARS in New Orleans, LA, Dr. C. W. Swanson, Program Planning and Review Staff and Ernest R. George, Contract Officer in the New Orleans

ARS Office. We will also send a copy to Mr. A. R. Robinson, Dr. D. A. Farrell, and Mr. C. W. Carlson, all of the National Program Staff, for their comments.

The previous review by ARS was very favorable and I do not expect that you will have any problems in completing the contract with Dr. Cooper.

The general cooperative agreements necessary to obtain the Universities' support have not yet been drawn. However, we have had enough discussion to indicate that there will be no problems in completing this.

You may be interested in the fact that for every 2 dollars we are requesting, we are contributing 1 dollar. This is of course due to the similarity of this project to ongoing research projects.

One of the reasons for our interest in the project is our (ARS) need for research data from a completely instrumented series of nested watersheds. The proposal, if funded, will still provide enough support to be of interest to us. We propose to add the dimension of water quality to the project at our own expense as funds become available. These data and such a facility are needed as a site for field testing and as an experimental laboratory for sediment and water quality related research. We plan to use the facility after the proposed project is complete for that purpose. Therefore, we appreciate the position the Corps of Engineers has taken with regard to ownership of the instrumentation after the project is terminated.

We sincerely appreciate your support of our research program as indicated by the willingness on your part to work with us. We are attempting to provide you with as good a research program as we can and hope that it meets your approval.

Sincerely,

Donn G. DeCoursey

Donn G. DeCoursey
Laboratory Director

Enclosure

cc:
B. R. Winkley
J. F. Henley
C. D. Ranney
A. W. Cooper
G. R. Swanson
A. R. Robinson
D. A. Farrell
C. W. Carlson
W. C. Little
E. R. George

DEPARTMENT OF THE ARMY
VICKSBURG DISTRICT, CORPS OF ENGINEERS
P. O. BOX 60
VICKSBURG, MISSISSIPPI 39180

REPLY TO
ATTENTION OF: LMKED-H

31 MAR 1977

Dr. Donn G. DeCoursey
Director, Sedimentation Laboratory
Agricultural Research Service
P.O. Box 1157
Oxford, Mississippi 38655

Dear Dr. DeCoursey:

I refer to your letter of 11 March 1977 in which you transmitted a proposal to undertake a project entitled "An Experimental Study of Streambank Stability". I accept your proposal to undertake this project.

We are forwarding a copy of this letter along with a completed form DA2544, Intra-Army Order for Reimbursable Services, in the amount of $1,225,600.00 to fund the first year of the study, to Dr. A. W. Cooper, Southern Regional Deputy Administrator of ARS in New Orleans.

Thank you very much for your interest in the Streambank Erosion Control and Demonstration Project. We are looking forward to a very productive relationship over the next four years.

Sincerely yours,

GERALD E. GALLOWAY
Colonel, Corps of Engineers
District Engineer

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

A PROJECT PROPOSAL
Submitted to
VICKSBURG DISTRICT U. S. ARMY CORPS OF ENGINEERS
DEPARTMENT OF DEFENSE
by
SEDIMENTATION LABORATORY
ALABAMA-NORTH MISSISSIPPI AREA
SOUTHERN REGION
AGRICULTURAL RESEARCH SERVICE
U. S. DEPARTMENT OF AGRICULTURE

P. O. Box 1157, Oxford, Mississippi 38655
Address of Organization

An Experimental Study of Streambank Stability
Title of Proposed Project

Amount Requested $2,743,500 Proposed Duration 4 yr Requested Starting Date 4/1/77

Name of Project Manager Dr. D. G. DeCoursey	Principal Investigator Dr. W. C. Little
Social Security No. 315-32-2392	424-32-3208
Title Laboratory Director	Research Leader
Telephone (w/area code) 601-234-4121 (comm)	601-234-4121 (comm)
Other No. 601-234-3872 (where message can be left)	601-234-2587
Organizational Affiliation ARS-USDA Sedimentation Laboratory	ARS-USDA Sedimentation Laboratory
Address if Different from Above	

	Endorsements Project Manager	Other Endorsements	Approving Administrative Official
Name			
Signature			
Title			
Date			

1.1 Executive Summary

This project proposes to investigate channel stability problems and solutions in Bluff-line tributaries draining into the Mississippi Delta in the Yazoo Basin. These tributaries are contributing sizeable quantities of sediment to Mississippi Delta streams, in particular the Yazoo River. Since these streams are almost flat, most of the sediment deposits; restricting the flood flow carrying capacity of the river, and creating severe problems with river traffic, requiring almost continuous dredging operations. The sediment not only creates problems in the Delta streams, but it also creates channel stability problems in the bluff line watersheds, as much of it comes from the channels themselves.

The proposed four-year project has five major objectives relating to a better knowledge of channel stability problems and improved methods of channel stabilization: (1) determining the influence of grade control structures on channel stability, (2) monitoring the performance of selected channel stabilization methods, (3) evaluating the effects of geology, geomorphology, soils, land use, and climate on runoff and sediment production from major source areas, (4) estimating the water and sediment production from a large mixed land use watershed and the integrated effects on channel stability, and (5) evaluating the relation between valley stratigraphy and channel morphology and their combined effects on channel stability.

Channel stability problems of these bluff line watersheds are similar to problems in many areas of the United States. The proposed project should help in providing solutions applicable to these problems. The first objective ultimately should provide criteria for determining the number of grade control structures needed on a particular stream for a stable channel. Results obtained from the monitoring of the various grade control and channel revetment techniques should provide information on the types and designs that are most effective and economical. Data collected on the watersheds will provide information about the influence of watershed management on channel stability and the effectiveness of specific stabilization techniques. The watershed and valley stratigraphic studies should be helpful in extending the results obtained in this study to other areas with similar problems.

The proposed project will include both field and laboratory research. Field research will consist of a series of streamflow and sediment monitoring stations located near some of the stream grade/bed control and streambank stability construction projects, to monitor their performance and measure the sphere of influence they have on the channel. A series of "nested" watersheds extending upstream from a major flow and sediment monitoring station on one of the major tributaries to source areas of runoff and sediment production will be instrumented to monitor the movement of water and sediment through the watersheds. Climatic conditions, soil moisture, groundwater levels, erosion rates, and surface water movement from major soils and geologic areas will be collected, analyzed and made available to the Corps of Engineers. Valley strati-

graphy, channel morphology and geologic data will be collected. Channel stability will be evaluated as to cause and mode of any observed failures. Laboratory studies to support the project will consist of model studies of grade control structures, and flume studies of resistance, turbulence, and sediment transport.

Initial efforts will be in the procurement of instrumentation for both the field and laboratory efforts and the location of streamflow measurement and watershed sites. Construction and installation of field equipment will begin in the latter part of this year and very likely continue throughout the life of the project. Most of the stations will be in operation by the end of FY 78, however, some construction and installation will be ongoing as equipment on the smaller sites is moved from one location to another as needed. Laboratory research on several aspects of the project are ongoing ARS research programs that will be expanded for this project. Others will be initiated as soon as supporting instrumentation are available.

This project will be supported within ARS by 9 specific research outlines that describe in detail the proposed channel stability research project. A significant part of the project will be contributed by ARS, making it a truly cooperative effort. We are asking for support at a rate of $1,225,600 for the first year, $543,100 for the second year, $543,900 for the third year, and $542,800 for the fourth year. The ARS contribution is $325,500 for the first year, $359,000 for the second year, $369,100 for the third year, and $393,500 for the fourth year. In addition, research facilities such as our flumes and existing instrumentation valued at nearly 1 million dollars will be devoted to this effort. The Laboratory recently acquired a computer system for data acquisition and evaluation. If it were not for this facility, the project would be difficult to undertake. Much of the ARS contribution will be in the form of professional and support help, nearly all of the resources of two of the research units and a sizeable contribution from three of the other units will be devoted to the project. Additional help will be obtained through General Cooperative Agreements with the University of Mississippi and Mississippi State University.

1.2 Descriptive Narrative

2.1 Introduction

The Yazoo River, a tributary of the Lower Mississippi River, flows through the Mississippi (State) Delta, a highly productive agricultural area. Because this land is some of the most productive in the country and has been subject to periodic flooding, the Corps of Engineers has completed extensive flood prevention projects. These consist of levees, channel improvements, land use management, and flood control reservoirs. Even though four major reservoirs have been placed on major tributaries to the Yazoo: Arkabutla, Sardis, Enid, and Grenada Reservoirs; sediment accumulation continues to be a major problem in the channels of the Yazoo Basin. Sediment

accumulations are creating two major problems: (1) decreased carrying capacity of the channel and (2) hazards to barge and ship traffic. Most of the sediment creating these problems is coming from numerous tributaries that flow into the flat Delta from the bluff line on the East. Much of this sediment originates in the channel beds and side walls of these streams. Sediment from tributaries above the four major reservoirs is trapped in them and is not a problem as far as the Delta is concerned.

The base level control of these bluff-line streams is the elevation of the Mississippi River. This elevation, and hence the base level control, has not been constant during recent geologic history, but has fluctuated between glacial lows and interglacial highs. The magnitude of the relief change is questionable. Fisk states the Mississippi Valley was entrenched 400 to 450 ft below present sea level during late Wisconsin glaciation (app. 250 ft entrenchment for the north Mississippi Delta). Saucier, on the other hand, states the sand and gravel "bottom" deposits in the Mississippi Valley may actually be pre-glacial. In either case the fluctuations of the ancestral Mississippi River also should be reflected in the valley deposits of the bluff-line streams. The continuity of the sequences of the bluff line valley deposits should serve as a useful "bench-mark" in relating the findings from this study to other areas of similar nature. Also, better definitions of the bluff line valley deposit sequences would possibly aid in a better understanding of the history of the Mississippi Valley itself.

Land use practices have drastically affected all the watersheds in the study area. Many watershed bottoms have as much as 12 feet of recent (post-settlement) alluvium deposited over presettlement soils or remnants thereof. The properties of these old soils are pertinent with respect to channel stability.

Land use by man has increased the runoff in many areas. Channelization for flood abatement has accentuated the erosive channel flows by steepening the channels and containing proportionately more of the total flow within them. Ponds and small flood control structures are trapping large quantities of sediment that would normally be satisfying the sediment carrying capacity of the channel system. Degradation initiated by these sediment deficiencies has often proceeded upstream, producing a new cycle of upland dissection. All of these activities directly affect channel stability and similarly the influence of geomorphological features which are frequently employed in channel stability studies, i.e., the geomorphological features may be inherited from past conditions and may not reflect present conditions.

Upland land use and management practices influence the rate and amount of surface runoff, the rate and amount of sediment production, and the physical and chemical characteritics of the produced sediment. These variables are prime determinates of the erosiveness of subsequent channel flow.

The "most feasible" approach to solution of channel stability problems includes either or both upland management practices and channel protection activities, i.e., grade control, fences, dikes, riprap, etc. The upland management practices are:

1. Those which influence the rate and amount of runoff.

2. Those which influence the rate and amount of sediment production.

3. Those which affect the size and type of sediment produced. In general, these practices include vegetative cover; tillage practices; control of surface sealing and/or restricted internal drainage; land shaping; erosion control and runoff management practices, and many others.

A great advantage of this approach to solving channel stability problems is that upland conservation management is combined with channel stability design on a watershed basis. It also maintains or enhances the crop productivity of the upland areas.

Problems of sediment accumulation in river channels and of bank instability initiated Public Law 93-251, a project designed to demonstrate the effectiveness of alternative bank revetment and stabilization practices, identify soil stability problems and causes of erosion, and make recommendations on means for the prevention and correction of streambank erosion. In order to accomplish this, a series of stabilization structures must be installed, and a data collection and evaluation program initiated to determine the local influence of the structures and the influence of upland management practices on their performance.

It is proposed to select one bluff-line tributary between Sardis and Grenada Lakes for detailed instrumentation and observation of the effectiveness of selected stabilization practices. A maximum of 10 to 12 stations is proposed in the study watershed. Revetment methods on additional tributaries will be monitored and their performance evaluated. At least six additional gaging stations will be installed.

Basically, the proposed project will characterize (1) the channel and flow conditions in the vicinity of major channel stabilization techniques, (2) the geomorphological features of the study area, and (3) watershed features including water and sediment source areas as a basis for assessing their influence on channel stability. It is proposed to conduct four years of extensive field and laboratory studies of selected measurable parameters. The channel and flow conditions will be characterized by stream discharge, sediment load, ground-water conditions and channel shape. The geomorphological features will be characterized by studying the channel morphology, watershed topography and valley stratigraphy. the water-

shed features will be characterized by an extensive data collection network of major climatic, hydrologic, soil, land use, and sediment parameters. Modeling of channel stability will be supported by laboratory studies of flow resistance, turbulent entrainment, and sediment transport.

2.2 Project Objectives

An extensive hydrologic monitoring of selected watersheds draining the bluff line along the Mississippi Delta in the Yazoo Basin will be initiated. In conjunction with this, detailed laboratory studies will be conducted to support the field studies. The specific objectives are:

3.1 Determine the influence of grade control structures on channel stability.

3.2 Monitor and evaluate the performance of selected types of channel stabilization methods installed in the study area.

3.3 To the extent possible, evaluate the effects of geology, geomorphology, soils, land use, and climate on runoff and sediment production from representative sites in major source areas within the study watershed.

3.4 Estimate the water and sediment production from large mixed land use watersheds and the integrated effects of these on channel stability.

3.5 Evaluate the relation between valley stratigraphy and channel morphology and their combined effects on channel stability.

2.3 Project Plan and Activity

The planned activity will be conducted simultaneously along 5 lines:

3.1 Evaluation of the effects of grade control structures on upstream aggradation, downstream degradation, bank seepage and stream reaeration.

3.2 Selection, installation, and operation of continuous monitoring stations for water and sediment discharge at selected channel stabilization sites.

3.3 Valley stratigraphy and channel morphology of channel stability.

3.4 Selection, installation, and operation of source area watersheds and subwatershed field sites for hydrologic and sediment data.

3.5 Laboratory studies of bank material detachment, flow resistance, turbulent entrainment, and sediment transport to aid in modeling streambank stability.

The first part of the project will consist of instrument procurement, selection of the reseach watersheds, and the location of major stream gaging sites. Many of these stations will be in operation by the second year of the study. If funds are available, additional stations will be added as needed. Some instrumentation, such as that used for soil water monitoring and erosion, will be moved from site to site during the period of the project.

These investigations will complement many of the programs at the USDA Sedimentation Laboratory as indicated by 8 individual research projects that have been prepared to document the Laboratory's involvement. The entire effort of the Stream Channel Stability Unit will be devoted to this study. Nearly all of the effort of the Sediment Transport Unit will be devoted to it. A significant contribution is also being made by the Hydrology and Erosion Units. The Sediment Deposition Unit is also contributing some effort. Thus, the Sedimentation Laboratory is contributing available expertise, equipment, instrumentation, and other facilities to the project. This contribution is being made because this study will strengthen the Laboratory's efforts to extend knowledge of sediment production and movement through a channel system and the resulting influence on channel stability.

2.4 Operational Plan

The proposed project will be conducted on bluff line tributaries of the Yazoo Basin and at the Sedimentation Laboratory, Oxford, Mississippi. The latter facility contains some 33,000 sq. ft. of floor area consisting of hydraulic, chemical and physical laboratories, offices, library, conference room and drafting, instrument and machine shops, computer and photographic facilities. The laboratory staff consists of engineers, soil scientists, geologists, chemists, mathematicians, and biologists. In addition, these scientists are supported by technicians, shop and office personnel. Active Cooperative Agreements are available with the University of Mississippi, Mississippi State University, and the University of Minnesota St. Anthony Falls Experiment Station for use in obtaining additional expertise as needed.

Laboratory facilities are available for preliminary studies on evaluation of water, sediment, and soil parameters. Instruments are available for performing many of the tests needed. Flumes are also available for the studies of flow resistance, turbulent

entrainment, and sediment transport. An excellent computer system is available for data acquisition, reduction, and evaluation.

Research facilities on the selected watersheds are nonexistent. While bank stabilization measures are being constructed under the Section 32 Program, watersheds and other flow measurement sites will be selected. Data collection will begin immediately using conventional instrumentation. As soon as most stations are in operation, a gradual shift will be made to more sophisticated but less labor oriented automatic recording devices. As soon as the source area watersheds are selected, instrumentation on soil moisture, erosion, pond water levels, crop growth, etc. will begin. Laboratory studies will begin immediately after instrumentation is completed. Model development for prediction of the influence of land use management on channel stability is already in progress.

Following the construction of the bank stabilization measures under the Section 32 Program, all sites will be monitored by ground photography and field observation quarterly and following major hydrologic events. Site surveys and aerial photography will be taken by the Corps of Engineers for use in the performance evaluation.

3.1 A Schedule of Project Activities is included in the following Table.

3.1 Schedule of Project Activities

4.1 Data Collection

```
    5.1 Watershed Studies                      Months since Project Approval
                                             6    12    18    24    30    36    42    48
        6.1  Planning                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.2  Literature Review          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.3  Design of Stations         XXXXXXXXXXXXXXX
        6.4  Construction of Stations         XXXXXXXXXXXX      XXX         XXX
        6.5  Equipment Purchases        XXXXXXXXX         XX          XX
        6.6  Install Equipment                XXXXXXXXXXXX      XXX         XXX
        6.7  Streamflow Data Collect.            XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.8  Channel Surveys               XXX         XXX         XXX         XXX
        6.9  Watshed. Characterization  XXXXXXXXXXXXXXX         XXX         XXX
        6.10 Soil Water Studies                     XXXXXXXXX   XXXXXXXXX   XXXXXXXXX
        6.11 Erosion Studies                           XXX         XXX         XXX
        6.12 Land Use Monitoring                    XXXXXXXXX   XXXXXXXXX   XXXXXXXXX
        6.13 Climatic Data Collect.           XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.14 Pond Studies                           XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

    5.2 Channel Studies

        6.1  Planning                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.2  Literature Review          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.3  Cont. of Stations                XXXXXXXXXXXX
        6.4  Equipment Purchases        XXXXXXXXX
        6.5  Install Equipment                XXXXXXXXXXXX
        6.6  Data Collection                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

    5.3 Laboratory Studies

        6.1  Planning                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.2  Literature Review          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
        6.3  Equipment Purchases        XXXXXX
        6.4  Install Equipment             XXXXXXXXX
        6.5  Data Collection                  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

4.2  Data Evaluation                            XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
4.3  Model Development                  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
4.4  Progress Report                                  XXX
4.5  Publication of Results                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
4.6  Model Evaluation                                       XXXXXXXXXXXXXXXXXXXXXXXX
4.7  Data Summary                                     XXX                        XXX
4.8  Final Report                                                                XXX
```

X = one month

2.5 Detailed Operation

Much of the proposed project is based on a complete hydrologic assessment of one tributary.

3.1 The data collection program for the watersheds is as follows:

4.1 Criteria for Site Selection

5.1 Watershed (See Figure 1)

6.1 Nested (one system)

7.1 Area drained by Station A = 10 - 50 sq. mi.

7.2 Area drained by Station B = 5 - 30 sq. mi.

7.3 No major tributaries should enter the channel between A and B.

7.4 Subcatchments selected for detailed observations should represent major land uses, geologies, soils, geomorphologies, and sediment source areas, and should be fairly homogeneous with respect to each characteristic.

7.5 The watersheds should be urbanized to the least possible degree.

6.2 Source Area

7.1 Additional source area watersheds will be selected to complement the catchments described above if funds are available.

5.2 Channels

6.1 A well defined channel should be a significant part of the drainage network between Stations A and B.

6.2 The main channel between A and B should also be an important source of sediment production and/or deposition.

4.2 Data to be Collected

5.3 Basin Characteristics

6.1 Channel Data

7.1 Instrument major tributaries above B (i.e., Stations C on Figure 1). Gages should be located in series or in tandem so as to measure as much inflow above each station as possible. Stations should be placed along the major tributary up to unit source size (Upper E Station).

7.2 At Stations A and B obtain:

8.1 Continuous records of stage, water discharge and temperature.

8.2 Continuous sampling records of total and suspended sediment load.

8.3 On selected storm events determine total and suspended sediment discharge and size distribution at points throughout the event.

7.3 At Stations of type C, D, and E obtain:

8.1 Continuous records of stage, water discharge and temperature.

8.2 Continuous sampling records of total sediment load.

8.3 On selected storm events determine total and suspended sediment concentrations and size distribution at points throughout the event.

7.4 Detailed cross-sectional surveys of the main channel between A and B, will be made annually and following major storm events throughout the year by the Corps of Engineers.

7.5 Detailed cross-sectional surveys of a few selected sections in some tribu-

taries above B will be made at repeated intervals by the Corps of Engineers.

7.6 Soil characteristics of the bank material will be mapped including particle size distribution, clay mineralogy, pH, liquid limits, etc.

6.2 Watershed Data - To be measured at various points over the watershed using a superimposed grid.

7.1 Geomorphology. Good quadrangle maps, detailed aerial photos with contour overlay, and field reconnaissance will be required to document topography and channel characteristics.

7.2 Geology. A detailed geological survey of the watershed will be required.

7.3 Soils. Texture and description of each soil profile will be made with the help of the Soil Conservation Service.

7.4 Land Use

8.1 Major land uses will be documented by means of aerial photo mosaics and ground surveys.

8.2 Type of vegetation, its canopy, and ground cover will be determined.

8.3 A sampling of interception storage capacity and crop stage will be obtained at selected sites during the crop season.

7.5 Soil-Water Monitoring of one or two Source Area Subcatchments (E size areas on Figure 1)

8.1 Infiltration rates will be determined using infiltrometer tests.

8.2 Soil moisture content will be monitored using both the neutron probe and the double gamma ray probe or gravimetric sampling in some cases.

8.3 Soil-water potentials will be monitored using porous-blocks.

8.4 Soil-moisture characteristics curves "moisture content-tension" and "moisture content-hydraulic conductivity" relationships will be developed if not now available.

8.5 Seasonal variation of infiltration will be determined if funds permit.

7.6 Soil-Water Monitoring of A, B, C, and D-type Subcatchments.

8.1 Soil moisture content and potential will be monitored at selected sites within the watersheds, depending upon the availability of funds.

7.7 Ground-Water Table

8.1 A general survey of the ground-water elevations in the watersheds will be made.

8.2 Seasonal variations of these elevations will be made at selected sites.

7.8 Surface-Water Impoundments

8.1 General Topographic surveys of major impoundments in the E type watersheds will be made.

8.2 Continuous records of pond stage will be collected at selected impoundments in the E type watersheds and at sites in the other watersheds. Records from staff gages will be collected at other sites.

8.3 Water and sediment discharge into and out of one impoundment in one of the F type watersheds will be collected.

7.9 Point Sources of Sediment (E size areas on Figure 1)

8.1 A significant gully source will be monitored to indicate the yield and characteristics of the eroded material.

8.2 Total and interrill erosion will be measured on the major soil types, crops and tillage conditions.

9.1 Field plot and row-side measurements of erosion runoff, infiltration, interception, and sediment characteristics data of major land uses will be collected.

6.3 Storm Data (continuous monitoring)

7.1 Establish one first order weather station.

8.1 The Class A weather station will include:

9.1 Total incoming solar radiation

9.2 Wind direction and intensity

9.3 Air, water, and soil temperature

9.4 Humidity

9.5 Class-A and insulated pan evaporation

9.6 Barametric pressure

6.7 Precipitation

7.2 Install 3 or 4 standard raingages in each of the subcatchments.

8.1 At least one site in each watershed will consist of both standard and pit type gages.

4.3 Requirements for Characteristic Variability and Length of Records

5.1 Characteristic Variability

6.1 As much varibility as possible in geology, geomorphology, soils and land use should be considered as a basic criteria in the selection of the series of nested watersheds described in Parts 4.1 and 4.2.

6.2 Other watersheds may be needed, outside the nested set, in order to obtain a reasonable range in land use, soils geology, and geomorphology. These will be established if funds are available.

6.3 All watersheds should be located within a 45-min. driving time of the Sedimentation Laboratory.

5.2 Length of Record

6.1 Some of the stations in the nested set will be retained for continued use as an environmental research laboratory to be used for Sedimentation Laboratory field research.

6.2 Some of the instrumented sites will be of a temporary nature, and equipment may be moved from place to place. Monitored sites will be retained only long enough to observe a range of storm sizes occurring on different antecedent conditions: two to four years at the most.

3.2 The data collection program for grade control structures is as follows:

4.1 Criteria for Site Selection

5.1 Grade control structures

To be located and constructed by Corps of Engineers as needed.

4.2 Data to be Collected

5.1 In addition to data collected under paragraph 2.5, the following data will be collected:

6.1 Water surface profiles through the structure.

6.2 Riprap failure.

6.3 Seepage through the structure.

6.4 Downstream bank seepage around the structure.

6.5 Trash accumulation.

3.3 The data collection program for valley stratigraphy and channel morphology studies include:

4.1 Various data identified in preceding paragraphs.

4.2 Identification of channel stratigraphic units.

5.1 Physical, chemical, and mineralogical compositional elements.

5.2 Micro- and macromorphology fabric elements.

5.3 Distribution of the units in the valley.

4.3 Detailed plan and cross-sectional surveys of main channels and selected tributaries.

5.1 Surveys to be made annually.

5.2 Additional surveys as required to characterize specific bank instability problems.

4.4 Visual inspection of channels to identify mode and cause of bank instability.

4.5 Laboratory studies to identify the detachability of representative bank materials.

4.6 Soil water content and potential will be monitored for channel bank materials.

4.7 Stresses involved in block failure will be monitored.

3.4 The data collection program for the laboratory studies of stream flow resistance, turbulence and sediment transport are:

4.1 Resistance to unsteady flow

5.1 Steady state channel resistance functions for an alluvial channel with bed material like that in the selected study watersheds will be developed. Laboratory experiments in steady uniform flow will include simultaneous automatic monitoring and computer analysis of depth, mean velocity, water surface and bed slope, water temperature, sediment transport, and length, amplitude, and frequency of bed configurations. All data to be taken simultaneously at 5 observation stations along the experimental flume.

5.2 Transient velocity channel resistance function. Laboratory experiments as above, except that preprogrammed changes in discharge with time will be imposed on initially established steady uniform flows. Data as above will be collected, and time changes in depth, water surface and bed slope, and bed forms will be computer analyzed as the data is collected.

5.3 Transient depth resistance function. Laboratory experiments as above, except that preprogrammed changes in flow depth will be imposed on initially established steady uniform flows, while the pump speed is adjusted to keep the discharge constant. Data as above will be collected, and time changes will be computer analyzed.

5.4 Hydrograph flow mathematical model of resistance. Preprogrammed time changes in both depth and discharge (hydrographs) will be imposed on initially established steady uniform flows. Data as above will be monitored and computer analyzed to formulate a mathematical model of the time changes in channel resistance during transient flows. Insight into parts of the model made obscure by the simultaneous variation of depth and discharge will be provided by the experiments employing separate-variable technique as described in 5.1, 5.2, and 5.3 above.

4.2 Turbulent Entrainment

5.1 Cross-sectional surveys will be made of the instantaneous point boundary forces exerted by turbulent flows on the boundary of prismatic channels. These measurements will include evaluation of the mean values, variances, and higher statistical moments of both the lift and drag boundary-force components.

5.2 Simultaneously, measurements of the cross-sectional distribution of time-averaged fluid velocity will be made. These data will be used in assessing the influence of secondary currents on the time and spatial distributions of boundary forces.

5.3 The measurements of boundary forces and fluid velocities will be conducted over a wide range of steady, uniform turbulent flows.

4.3 Sediment Transport

5.1 The Sedimentation Laboratory's 250' long 9' wide test channel will be adapted to control both flow depth and discharge independently to study bed material transport.

5.2 A matrix of flow depths and rates will be studied allowing the system to reach equilibrium for each combination of depth and flow rates. Data will be collected as follows:

6.1 Total bed material load sampled at the pump intakes.

6.2 Water surface slope determined from at least 10 points along the flume.

6.3 Bed slope determined from ultrasonic sensors traversing the flume both laterally and along its length.

6.4 Flow depths determined from 6.2 and 6.3.

6.5 Flow rate fixed at selected values and controlled by the pumps.

6.6 Bed form properties: both spatial and temporal variability in bed form will be monitored and size distributions determined.

5.7 Total load separated into bed load and suspended load.

5.8 These data will be incorporated into a model for sediment transport to aid in estimating the effects of different field conditions on transport and channel stability.

2.6 Utilization Plan

The proposed project will collect data as indicated. These data will be tabulated, processed, and placed in a readily accessible data storage and retrievable system on USDA Sedimentation Laboratory computer. They will be available to any one so designated by the Corps of Engineers or the Sedimentation Laboratory. They will be used along with the laboratory studies of flow resistance, turbulent entrainment, and sediment transport to develop a model of sediment transport and streambank stability.

An interim report will be prepared at the end of FY 1979 describing progress to date. A final report will be prepared at the end of FY 1980. The results of the study will be publicized through technical reports, seminars, and technical publications. All pertinent details on installations, management techniques and benefits will be made available to the public.

The Project Manager, Principal Investigator, associates and advisory personnel are members of various national professional organizations and technical papers and reports presented before these bodies in technical sessions will publicize this activity. All participants and supporters of the work reported will be identified. Joint reports and papers with personnel of the U. S. Army Corps of Engineers, the U. S. Soil Conservation Service, various state universities, and other federal and state agencies are anticipated.

The progress report and a final summary report will be provided the U. S. Army Corps of Engineers and other interested and cooperating agencies. Evaluation of the accumulated results will appear in occasional reports, in technical papers and in the final report.

1.3 Project Proposal Budget

2.1 The proposed project budget is summarized in the accompanying table.

2.2 Details of proposed expenditures are available at the Laboratory in the Research Outlines describing the 9 specific studies that support this proposal.

2.3 Both the University of Mississippi and Mississippi State University are interested in cooperating with us. Thus, all of the funds shown on the budget for salaries to be paid by the Corps of Engineers will be expended through General Cooperative Agreements with them.

2.4 Some of the funds shown as miscellaneous will be used to contract items such as soil and sediment sample analyses.

3.1 Project Proposal Budget Summary

		Year I		Year II		Year III		Year IV	
		CE	APS	CE	APS	CE	APS	CE	APS
4.1	Salaries								
	Professional								
	Project Manager								
	Principal Investigator		86,600	25,000	110,700	25,000	115,200	25,000	120,100
	Associate Investigator	37,500	74,100	66,000	[illegible]	67,000	91,500	67,000	91,600
	Other Personnel								
	Technician	21,400	19,700	61,100	21,400	61,800	22,000	60,400	23,000
	Labor	12,000	1,300	13,300	1,100	14,100	1,100	14,200	1,100
	Secretary	1,760	2,400	12,000	3,100	12,100	3,300	14,500	3,300
	Graduate Student	13,000		24,000		24,500		25,000	
	Total Salaries	84,960	184,300	202,100	216,600	204,500	223,100	206,000	229,300
4.2	Staff Benefits	12,500	18,500	29,700	21,700	30,100	22,400	30,400	34,100
4.3	Total Salaries plus Benefits	97,400	202,800	231,300	238,300	234,600	245,500	237,300	263,400
4.4	Equipment	663,500	20,500	20,000	5,500	18,900	5,500	18,700	5,500
4.5	Materials and Supplies	90,500	8,600	23,300	6,000	24,700	6,000	21,600	6,000
4.6	Travel	8,500	3,300	10,600	5,100	11,100	5,100	10,600	5,100
4.7	Publication & Similar Type Costs	1,000	2,600	3,000	4,000	3,500	4,000	2,800	4,000
4.8	Computer Costs	91,000	1,500	6,000	1,500	6,000	1,500	6,000	1,500
4.9	Miscellaneous Costs	20,300	1,000	61,300	1,000	61,300	1,000	61,300	1,000
4.10	Total Costs Other than Salaries (4.4-4.9)	874,900	37,700	129,200	23,100	125,500	23,100	122,000	23,100
4.11	Total Direct Costs (4.3 + 4.10)	972,300	240,500	361.000	261,400	360,100	268,600	359,300	286,500
4.12	Sedimentation Laboratory Overhead	39,300	35,100	38,300	42,500	38,300	43,700	38,200	46,500
4.13	Subcontract Overhead	26,900		60,600		61,400		62,100	
4.14	Subtotal	1,037,600	275,600	459,900	303,900	459,800	312,300	459,600	333,000
4.15	ARS Overhead 18%	187,900	49,900	83,200	55,100	83,200	56,000	83,300	60,500
4.16	Total	1,225,500	325,500	543,100	359,000	543,000	368,100	542,900	393,500

Project 20008-60

CHANNEL STABILITY AS INFLUENCED BY WATERSHED PROCESSES, VALLEY STRATIGRAPHY AND GRADE CONTROL

General Objectives:

Most streambank stability studies have been concerned with protection measures at a specific site and looked only at the channel in the immediate vicinity to identify possible problems. There are many factors, however, controlling the stability of a given stream. Some of these are (1) upland management practices (controlling the sediment input to the stream), (2) valley stratigraphy (the material into which the channel is incised) and (3) grade control (natural or artificial controls of the elevation of the channel bed). These factors are not independent and all must be considered in determining the most feasible and practical method of providing bank and bed stability. This study will attempt to define and integrate the combined effects of these factors on streambank stability.

"RESEARCH PROJECTS AND OUTLINES"

<u>Section 1:</u> Stream bank stability as influenced by upland watershed processes (2[illegible]-61)

<u>Personnel Involved:</u> W. C. Little, E. H. Grissinger, J. B. Murphey, and F. H. Hawks

<u>Specific Objectives:</u>

1. Determine the effectiveness and feasibility of existing and newly constructed bank revetment materials on bank stability and channel regime.

2. Evaluate the effects of geology, geomorphology, soils, land use, and climate on water and sediment production by upland watersheds.

3. Evaluate the influence of sediment properties (particularly bed material properties) and sediment discharge on bed and bank stability.

<u>Expanded Statement of Problem:</u>

The Corps of Engineers was authorized in Section 32 of the <u>Water Resources Development Act of 1975, Public Law 93-251</u> to undertake an evaluation and demonstration project of streambank erosion control. The Corps of Engineers' "Plan of Study" for this project states as follows:

> "This report will discuss the feasibility of all methods of stabilization, especially any new method, identify soil stability and causes of erosion, and make recommendations on means for the prevention and correction of streambank erosion."

The two items from this quotation of particular interest are:

1. . . . the feasibility of <u>all</u> methods . . .
2. . . . means for the <u>prevention</u> . . .

Whereas most similar studies have been concerned with site specific protection measures (such as jacks, fences, bed control structures, etc.), the charge for this study mandates that this study include an evaluation of the response of the stream system (regime) to upland management practices and the influence of this response on bed and bank stability.

Certainly, upland management considerations influence the rate and magnitude of surface runoff, the rate and magnitude of sediment production, and the nature of the produced sediment. These variables are prime determinates of the erosiveness of subsequent channel flow. A "most feasible" approach to the problem of channel stability thus requires the inclusion of these latter three variables.

<u>Research Approach Including Analytical Treatment:</u>

Two or three watersheds will be highly instrumented for the measurement of water and sediment discharge. Instrumentation within the watersheds will be located so as to define 1) subcatchments representing major land use, geology, geomorphology, and soil conditions and 2) several series of nested watersheds (this data needed for routing). Routine data collection is specified in the attachment entitled "Research Watershed Requirements". Additional data includes the following:

1. Detailed soils and geologic investigations to define the possible occurrence of aquatards or aquacludes.

2. Evaluate the effectiveness of bank revetment methods. Where failures occur, determine mode and cause of failures.

3. Evaluation of the occurrence and properties of gravel deposits and other bed-type materials, and how these affect the regime of the channel.

The data will be analyzed using a process-simulation watershed model being developed at the USDA Sedimentation Laboratory. Full development of such a model would result in optimum utility of the results of this study; and the "most feasible" approach to solution of channel stability problems would include either or both upland management practices and channel protection activities, i.e., fences, dikes, riprap, etc. The upland management practices considered at this time include:

1. Those which influence the rate and volume of runoff.

2. Those which influence the rate and amount of sediment production.

3. Those which regulate the size and type of the produced sediment.

In general these practices then include vegetative cover, tillage practices, control of surface sealing and/or restricted internal drainage, land shaping, contouring, etc.

Of course, the great advantage of this approach is that upland conservation management is combined with channel stability design on a watershed basis. This study, through use of the process-simulation model will provide a means of assessing changes in channel regime as a result of changes in management practices or land use changes.

Research Watershed Requirements
USDA Sedimentation Laboratory

I. Criteria for Site Selection

A. Watersheds (see map)

1. Nested watersheds

a. Area drained by Station A = 10-50 sq. mi.

b. Area drained by Station B = 20-30 sq. mi.

c. No major tributaries should enter the channel between A and B.

d. Subcatchments selected for detailed observations should represent major land uses (geology, soils and geomorphology) and should be fairly homogeneous with respect to each characteristic.

e. The watershed should be urbanized to the least possible degree.

2. Source area watersheds--in addition to the nested watersheds, these are needed to characterize source input to system.

B. Channel

1. A well defined channel should be a significant part of the drainage network between Stations A and B.

2. The main channel between A and B should also be an important source of sediment production.

II. Data to be Collected

A. Basin Characteristics

1. Channel data

a. Instrument all major tributaries above B (i.e., Stations C on map). Gages should be located in series or in tandem so as to measure at least 60% of all inflow above every station. Stations should be placed along the major tributary (following these criteria) up to unit source size (Upper E Station).

b. At Stations A and B obtain:

1) Continuous records of stage, water discharge, water temperature, and total sediment discharge.

2) Continuous sampling records of suspended sediment load.

3) On selected storm events determine sediment size distribution.

c. At Stations of type C, D, and E obtain:

1) Continuous storm records of stage, water discharge, water temperature, and total sediment discharge.

2) On selected storm events determine suspended sediment concentrations and particle size distribution.

d. At Stations (to be selected) for source area watersheds--these will probably be fairly small watersheds:

1) Continuous storm records of stage, water discharge, water temperature, and total sediment discharge.

2) On selected storm events determine suspended sediment concentrations and particle size distribution.

e. Gauged water stage recorders at specific reaches to measure water surface profiles.

f.* Detailed plan and cross-sectional surveys of main channel between A and B will be made annually and following major events throughout the year.

g.* Detailed plan and cross-sectional surveys of a few selected sections in some tributaries above B will be made at repeated intervals.

2. Watershed data

a.* Geomorphology. Standard geomorphometric parameters will be determined from topographic maps and aerial photographs.

b. Geology. The general geology of the watersheds will be established from the literature.

c. A description of each soil will be made with the help of the Soil Conservation Service.

d. Land use.

1) All major land uses will be documented by means of aerial photo mosaics and ground surveys.

2) Type of vegetation, canopy, and ground cover will be determined.

3) A continuous monitoring of interception storage capacity and crop stage will be maintained at selected sites over the crop season.

e. Soil-water monitoring of D-type subcatchments.

1) Infiltration rates will be determined for each soil type using infiltrometer tests.

2) Soil moisture content will be monitored using both the neutron probe, and the double gamma-ray probe or gravimetric sampling in some cases.

3) Soil-water potentials will be monitored using porous-blocks.

4) Soil-moisture characteristics curves "moisture content-tension" and "moisture content-hydraulic conductivity" relationships will be developed for each soil type if not now available.

5) Seasonal variations of (1), (2)-neutron and double gamma probe and (3) will be determined at a few selected subcatchments.

f. Soil-water monitoring of A, B, C, and E-type subcatchments.

Soil moisture content and potential will be monitored at selected sites within the watersheds.

g. Ground-water table (including perched tables).

1) A general survey of the groundwater elevations for entire watershed will be made.

2) Seasonal variations of these elevations will be made at a few selected sites.

h. Surface-water impoundments.

1) General topographic surveys of all impoundments in the watershed will be made.

2) Continuous record of both stage and suspended sediment discharge will be collected at selected impoundments.

i. Point sources of sediment (gullies).

Significant point sources of sediment will be monitored to indicate the yield and characteristics of the eroded material.

B. Storm Data (continuous monitoring)

Establish two first order weather stations for the entire watershed, and install 3 or 4 raingages in each of the subcatchments.

1. In addition to the regular raingages, the quality of precipitation will be monitored at selected sites.

2. The Class A weather station will include:

a. Total incoming solar radiation.

b. Wind direction and intensity.

c. Air, water, and soil temperature--soil temperature will be determined for a series of soil-vegetative cover complexes.

d. Humidity.

e. Class-A pan evaporation.

III. Requirements for Characteristic Variability and Length of Records

A. Characteristic Variability

1. As much variability as possible in land use, soils and topography should be considered as a basic criteria in the selection of the series of nested watersheds described in Parts I and II.

2. Other watersheds may be needed, outside the nested set, in order to obtain a reasonable range in land use, soils, and topography.

3. All watersheds should be located as close as possible to the Sedimentation Laboratory.

E. Length of Record

1. Some of the stations in the nested set will be retained for an indefinite period as an environmental laboratory to be used for Sedimentation Laboratory field research.

2. Many of the watersheds will be of a temporary nature and may be moved from place to place. They will be retained only long enough to observe a range of storm sizes occurring on different antecedent conditions; two to four years at the most.

*Data acquired under other outlines.

Table 1. Schedule of Project Activities

```
                                            Months since Project Approval
                                       6    12    18    24    30    36    42    48

 1.  Planning                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.  Literature Review            XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.  Gaging Station Design        XXXXXXXXXXXX
 4.  Equipment Purchases          XXXXXXXXXXXX         XXXXXX         XXX
 5.  Installation of Equipment    XXXXXXXXXXXXXXXXXXXXXXXX      XXXXXX   XXXXXX
 6.  Data Collection                       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 7.  Data Evaluation                          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 8.  Data Analysis                                  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 9.  Publicize Results                                    XXX                  XXX
10.  Final Report                                                            XXXXXX
```

X = one month

Budget Summary - Watershed Processes - NRU [illegible]-61 - 4-12-77

		Year I		Recurring	
		CE	ATS	CE	ATS
4.1	Salaries				
	Professional				
	Project Manager				
	Principal Investigator		21,000	25,000	22,000
	Associate Investigator		8,700		9,500
	Other Personnel				
	Technician	10,000		34,000	
	Labor				
	Secretary			5,000	
	Graduate Student	5,000		6,000	
	Total Salaries	15,000	29,700	70,000	31,500
4.2	Staff Benefits	2,2[illegible]	3,000	10,300	3,100
4.3	Total Salaries plus Benefits	17,2[illegible]	32,700	80,300	34,600
4.4	Equipment	375,[illegible]	1,500	10,000	2,500
4.5	Materials and Supplies	41,[illegible]	2,500	10,000	3,000
4.6	Travel	[illegible]	1,000	2,000	1,000
4.7	Publication & Similar Type Costs	1,[illegible]	500	1,000	
4.8	Computer Costs	[illegible]1,[illegible]	1,500	2,000	1,000
4.9	Miscellaneous Costs	1[illegible],[illegible]	1,000	28,700	500
4.10	Total Costs Other than Salaries (4.4-4.9)	5[illegible],[illegible]	8,000	53,700	8,000
4.11	Total Direct Costs (4.3 + 4.10)	[illegible]27,[illegible]	40,700	134,000	42,600
4.12	Sedimentation Laboratory Overhead	21,[illegible]	10,000	13,600	8,000
4.13	Subcontract Overhead	[illegible],[illegible]		20,400	
4.14	Subtotal	5[illegible]4,[illegible]	50,700	168,000	50,000
4.15	ATS Overhead 18%	101,[illegible]	9,200	30,400	9,200
4.16	Total	[illegible]65,[illegible]	59,900	198,400	59,200

Section 2: Channel stability as controlled by valley stratigraphy (20808-62)

Personnel Involved: W. C. Little, E. H. Grissinger, J. B. Murphey, and P. H. Hawks

Specific Objectives:

1. To identify the distribution and properties of stratigraphic units within the geologically recent valley alluvial deposits.

2. To establish association between bank instability and the properties of the stratigraphic units and their sequences.

3. To develop predictive capabilities for defining the sequence of stratigraphic units within the alluvial valley deposits.

Expanded Statement of Problem:

A material fails whenever the sum of the several erosive forces is greater than the strength or erosive resistance of the particular material. The erosive forces incude such items as: 1) the action of flowing water inducing discrete particle scour; 2) the influence of ground water seep; 3) mass instability, i.e., gravity flow or slough; 4) the action of water infiltration into previously dry bank materials; and 5) other miscellaneous items such as particle abrasion, cattle tramping, etc. Frequently, these several erosive forces do not act independently, and the action of one (erosive agent) affects or magnifies the action of another. As an example, toe removal by discrete particle scour may decrease mass stability to gravity flow or slough. Similarly, ground water seep may affect both mass stability and the resistance of the material to discrete particle scour.

Channel banks, however, are usually composed of several different materials representing different stratigraphic units. In addition to the composition of each individual unit, the stability of the bank also depends upon the relative position of the several units, the continuity of each unit, and its large-scale morphology. Examples of extreme instability have been observed to be associated with situations where 1) an erodible (bank) toe material was overlain by relatively stable material, and 2) one of the stratigraphic units functioned as an aquatard or aquaclude thereby affecting the stability of the overlying material.

This study will be initiated to identify the nature and distribution of the various stratigraphic units within the geologically recent valley alluvial deposits and to establish associations of bank instability problems with typical sequences of the various units. If the results of this exploratory study indicate the stratigraphic units are definable and that their position is predictable, the study will be expanded. Results of the expanded study would complement current studies of the Stream Channel Stability Research Unit, USDA Sedimentation Laboratory.

Background and Field Reconnaissance:

1. Background

A. Geologic setting.--The base level control of the bluff line streams is the elevation of the Mississippi River. This elevation and hence the base level control has not been constant during recent geologic history, but has fluctuated between glacial lows and interglacial highs. The magnitude of the relief change is questionable. Fisk states the Mississippi Valley was entrenched 400 to 450 ft below present sea level during late Wisconsin glaciation (app. 250 feet entrenchment for the North Mississippi Delta). Saucier, on the other hand, states the sand and graveliferous sand "bottom" deposits in the Mississippi Valley may actually be preglacial. In either case, to some degree, the fluctuations of the ancestral Mississippi River should also be reflected in the alluvial valley deposits of the bluff line streams. The continuity of the sequences of the bluff line valley deposits should serve as a useful "benchmark" in relating the findings from the study watersheds to others of similar nature. Also, better definitions of the bluff line valley deposit sequences would possibly aid in better understanding the history of the Mississippi Valley itself. These aspects match our study with Ray Daniels.

B. Cultural Setting.--Land use practices have drastically affected all the watersheds in the study area. Many watershed bottoms have 4 to 12 feet of recent (postsettlement) alluvium deposited over presettlement soils, or remnants thereof. The properties of these old soils are pertinent with respect to channel stability.

Land use by man has increased both runoff rate and volume in many areas. Channelization for flood abatement has accentuated the erosive channel flows by containing more of the discharge within the channel thus increasing the average velocity. Degradation, caused by increased velocities, has in some instances proceeded upstream and initiated a new cycle of upland dissection. The proceeding directly affects stability and similarly affects the significance of geomorphology features which are frequently employed in channel stability studies, i.e., the geomorphological features may be inherited from past conditions and may not reflect present conditions.

2. Field Reconnaissance

As a part of our current studies of channel bank stability, we have taken several field trips with Ray B. Daniels, Soil Scientist, SSIU, SCS. Daniels has summarized our findings for the loessial areas of Mississippi, Tennessee, and Arkansas in memos dated June 19 and July 28, 1975 (copies attached) wherein he stated:

"The sequence of alluvial fills found in the Tennessee watersheds is very similar to that described earlier for the Mississippi watersheds. The major alluvial beds are silt loams with a PI less than 7 and a D_{50} of less than 0.05 mm. These beds make up the major part of the channels and are well within the limits of the tractive force study. It is of interest to me that the alluvial fills inspected in Tennessee were derived largely from a Memphis and Memphis-Loring landscape, whereas those in Mississippi were derived largely from a Loring-Grenada-Coastal Plain landscape. These relations suggest that the characteristics of the alluvial fills are zoned by soil association areas, a very reasonable assumption since the fills are derived from the soil of the watershed."

The typical sequence of alluvial fills in north Mississippi is: A post-settlement alluvium, 2-6 ft thick, overlies a pre-settlement soil, 10-15 ft thick, which in turn overlies alluvium varying from sand, to organic, to dense silty material. The post-settlement alluvium has been found by S. C. Happ to be a widespread surficial valley deposit ranging in thickness up to 10 or more feet. The pre-settlement soil, a paleosol, is sometimes found as a complete profile but more frequently only the lower horizons are present. The B horizon of these paleosols has a characteristic polygonal structure that measures 1 to 3 ft across. Frequently the polygonal structure has developed to such a degree that the individual polygons are not stable when exposed on channel banks. As noted above, the base alluvium is variable. The dense silty material is usually characterized by a highly developed polygonal structure thought to be pedogenically separate from that of the paleosol. The polygonal structure in this base alluvium has sharp interfaces usually with thin iron deposition around the edges of the polygons. These polygons measure 1-1 1/2 ft across. Usually this material is also laced with numerous root-hole or crayfish-burrow fillings. Frequently this deposit is underlain by unconsolidated sands.

We have observed frequent situations where massive bank instability was associated with the occurrence of unconsolidated sands under well developed paleosols. Cracks develop along the structural planes within the paleosol, and these cracks are enlarged by seepage and overbank flow. Stream flows undercut the unconsolidated sands, resulting in failure of the mass. We have also observed several sites where the stream channels are "relatively stable" at present but where the "stable" beds, usually dense silty material, are underlain by unconsolidated sand lenses. At several locations, the observed thickness of the "stable" beds is presently minimal, and severe instability problems could result from any further bed degradation.

Research Approach, Procedures, and Analytical Treatment:

The initial phase of this study will be restricted to the loessial (bluff line) area of north Mississippi. Identifiable stratigraphic units exposed along stream banks and cored at selected ranges across the

valleys will be mapped. All units will be sampled for laboratory analyses and, whenever possible, the units will be classified. Organic deposits will be sampled for age determination by carbon dating in an attempt to find similarities between watersheds. Morphological features of all units will be fully described. Unstable bank conditions will be visually classified as to probable mode of failure, and the location and occurrence of all "atypical" conditions will be noted (such as seep zones, natural bed controls, gravel bars, etc.).

Detailed plan and cross-section surveys of all alluvial channels will be made at the initiation of this study and will be repeated annually and following major events throughout the year. The initial survey will "monument" areas of interest which will be investigated in greater detail throughout the study time. Geomorphological parameters, soils and other pertinent information will be developed as necessary. Piezometers will be installed at selected locations to evaluate ground water seep, and soil water content and potential will be monitored along the channel boundary.

Stability of the channel bank materials, i.e., the various stratigraphic units, will be evaluated by appropriate field and/or laboratory tests. These tests will include 1) evaluation of material resistance to particle detachment and 2) evaluation of bulk properties associated with mass shear failure or slough. Characteristic properties of the bank material will be determined and related to the stability tests. These characteristics include micro and macro morphology, chemical, mineralogical and physical properties, and stratigraphic sequences.

Analytical treatments for the preceding will include 1) discriminate analysis to establish the integrity of the various stratigraphic units as mapped and to establish their significance with respect to channel geometry and morphology. 2) Regression analysis to establish the significance of characteristic properties with respect to mode of failure. 3) From the preceding, determine if a predictive model can be formulated.

If the distribution of stratigraphic units is definable within the study valleys and the units are shown to significantly influence bank stability, the study would be expanded in an attempt to identify predictive parameters, i.e., parameters which could be used in predicting the occurrence of stratigraphic units, particularly those which are critical in relation to bank stability. The soil association in the valleys would probably be of little direct value since these soils are within the post-settlement alluvium. It may be possible, however, to utilize these soil associations by correlation with the paleosols or other pre-settlement stratigraphic features. The valley stratigraphy may be zoned or correlated with the upland soil associations. Such a relation would be of immediate utility due to the present day knowledge of these (upland) soils. Additional information might be obtained by using Daniels' interpretation of the Peoria-Roxana interface.

The representativeness of the study watersheds will be established by determining certain of the parameters for watersheds outside the study area. These parameters include the stratigraphic sequences of the alluvial valley deposits, the channel geometry and morphology, and the geomorphic parameters.

Table 1. Schedule of Project Activities

```
                                             Months since Project Approval
                                         6    12    18    24    30    36    42    48

 1. Planning                        XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2. Literature Review               XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3. Channel Reconnaissance          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4. Design of Initial Strati-        XXXXXXXXX
    graphic Investigation
 5. Initial Stratigraphic                 XXXXXXXXXXXX
    Investigation
 6. Equipment Purchase                    XXXXXX
 7. Install Equipment                     XXXXXXXXX
 8. Field Stations Operational              XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 9. Sample Analyses                             XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
10. Establish Cross Section         XXXXXXXXXXXXXXXXXX
11. Field Station Debugging               XXXXXXXXXXXXXXX
12. Preliminary Data Evaluation                 XXXXXX
13. Design Detailed Stratigraphic               XXXXXXXXXXX
    Investigation
14. Detailed Stratigraphic                            XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    Investigation
15. Data Evaluation                                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
16. Model Development                                       XXXXXXXXXXXXXXXXXXXXXXX
17. Model Evaluation                                                  XXXXXXXXXXXXX
18. Data Summary                                       XXXXXXXXXXXXXXXXXXXXXXXXXXXX
19. Reports                                              XXX                 XXXXXX
```

3.1 Project Proposal Budget Summary

		Year I CE	Year I ARS	Recurring CE	Recurring ARS
4.1	Salaries				
	Professional				
	Project Manager				
	Principal Investigator				
	Associate Investigator	12,000	43,500	14,000	51,000
	Other Personnel				
	Technician		10,600		11,100
	Labor	4,000		3,000	
	Secretary			5,000	
	Graduate Student	5,000		6,000	
	Total Salaries	21,000	59,100	33,000	62,100
4.2	Staff Benefits	3,100	5,900	4,000	6,200
4.3	Total Salaries plus Benefits	24,100	65,000	37,000	68,300
4.4	Equipment	68,700	2,000	5,000	2,000
4.5	Materials and Supplies	6,000	1,500	5,000	1,500
4.6	Travel	2,000	500	6,000	500
4.7	Publication & Similar Type Costs			2,000	500
4.8	Computer Costs			2,000	500
4.9	Miscellaneous Costs	5,000		24,600	500
4.10	Total Costs Other than Salaries (4.4-4.9)	83,700	4,000	44,600	5,500
4.11	Total Direct Costs (4.3 + 4.10)	107,800	69,000	82,500	73,800
4.12	Sedimentation Laboratory Overhead	4,600	8,000	9,400	11,000
4.13	Subcontract Overhead	6,300		9,800	
4.14	Subtotal	118,700	77,000	101,800	84,000
4.15	ARS Overhead 18%	21,300	14,000	18,200	15,300
4.16	Total	140,000	91,000	120,000	100,100

Section 3: An experimental model study of low-drop grade control structures (29800-63)

Personnel Involved: W. C. Little and J. B. Murphey

Specific Objectives:

1. Determine the optimum dimensionless geometry of energy dissipation pools for various geometric shapes of low-drop rock riprap structures to provide maximum energy dissipation. This will also include subcritical chute structures using riprap for energy dissipation.

2. Evaluate existing riprap sizing criteria specifically for grade control structures.

3. Verify the model studies with prototype structures.

Statement of the Problem:

Many low-drop grade control structures, constructed of rock riprap have been installed in Southeastern States by the Soil Conservation Service. To the writer's knowledge, none have been designed with stilling basins for energy dissipation. Consequently, scour holes have developed immediately downstream in a random fashion and in many cases have caused downstream bed degradation and bank sloughing. The channel bed degradation causes the effective drop across the structure to increase, hence eroding a larger scour hole. The stone on the downstream toe of the structure fall into the scour hole, ultimately causing failure of the entire structure. An uncontrolled headcut then proceeds upstream causing bank instabilities to occur.

To alleviate this problem, an excavated and stabilized energy dissipation pool must be an integral part of the design of the drop structures. To prevent downstream erosion the energy from the drop must be dissipated in turbulence within the energy dissipation pool. The geometry of the energy dissipation pool is a function not only of the geometry of the drop structure but also of the flow properties. Several model studies have been conducted for 2-dimensional drops but these results are not directly applicable to trapezoidal channels.

The dimensionless geometry of the energy dissipation pool relative to the geometry of the drop structure and the discharge must be determined.

When these drop structures are constructed of rock, the rock in the control section of the structure is generally on a steep slope and very vulnerable to attack from the supercritical flow. Riprap sizing criteria must also be evaluated in critical areas of the rock riprap structures.

Literature Review:

Shape of Scour Hole

Work by Murphy (4) and Robinson (5) indicates that the length of the scour hole is the same order of magnitude as the width. The dimensions of the scour holes given by Murphy (4) were determined from field observations after a scour hole had developed in the natural earth material. Of course, this technique should give the maximum dimensions for a scour hole and would be larger than needed where the scour hole is to be preformed and lines with riprap.

The structures designed and tested at the U. S. Waterways Experiment Station (4) provided a depth of scour hole (below downstream grade) approximately equal to the height of drop where the scour holes were preformed and lined. However, as one would expect, Fletcher and Grace (3) have shown that the depth of scour hole is a function of the discharge.

Riprap Size

Taking Andersons critical shear stress criterion (1) for riprap sizing

$$\tau_c = 4\ d_{50} \tag{1}$$

and converting the shear stress to a velocity as Blaisdell (2) has done gives

$$d_{50} = 0.00116\ \frac{V^2}{\sqrt{y}} \tag{2}$$

Where d_{50} is the mean size of material, V is the velocity, and y is the depth.

The advantage of this approach is that the velocities at the brink of the drop structure can be defined more precisely than the shear stress. The velocity in the control section (throat of drop structure) will be the critical velocity, V_c.

Research Approach and Procedure:

The channels in which these prototype drop structures will be installed have bottom widths from a few feet up to around 100 feet. Discharges range from a few hundred cubic feet per second up to 25,000 cfs. Hydraulic models covering these ranges of channel sizes and discharges will be constructed in the laboratory in order to provide generalized results. Various model to prototype scale ratios will be used to cover the necessary range of variables and permit the overall model to fit existing physical facilities. Standard fluvial modeling techniques using Froude similitude will be used.

Crushed limestone will be used as the model riprap material. Observations of any movements of the riprap will be recorded and compared with existing criteria for sizing of the stone.

Data to be Taken:

Parameters to be controlled.

1. Shape of drop structure

2. Discharge

3. Water temperature

4. Riprap size

Parameters to be measured:

1. Flow depths at all pertinent points

2. Flow velocities

3. Discharge

4. Turbulence upstream and downstream from drop structure

5. Shape of scour hole

References Cited:

1. Anderson, A. G., Paintal, A. S., and Davenport, J. T. Tentative design procedure for riprap-lined channels. National Academy Engineering. Natl. Coop. High Research Program. Report 108, 75 pp. 1970.

2. Blaisdell, Fred W. Model test of box inlet drop spillway and stilling basin proposed for Tillatoba Creek, Tallahatchie County, Miss. U. S. Dept. of Agriculture, Agricultural Research Service, ARS-NC-3, 59 pp. Jan 1973.

3. Fletcher, B. P., and Grace, J. L., Jr. Practical guidance for estimating and controlling erosion at culvert outlets. U. S. Waterways Experiments Station, Misc. Paper H-72-5, 39 pp. May 1972.

4. Murphey, Thomas E. Control of scour at hydraulic structures, ASCE, National Water Resources Engineering Meeting, Preprint 1288, 18 pp. Jan. 1971.

5. Robinson, A. R. Model study of scour from cantilevered outlets. Transactions, Am. Soc. of Agricultural Engineers, Vol. 14, No. 3, pp. 571-581. 1971.

Table 1. Schedule of Project Activities

		Months since Project Approval							
		6	12	18	24	30	36	42	48
1.	Planning	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX		
2.	Literature Review	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	
3.	Similitude Design	XXXXXX				XXXXXX			
4.	Purchase Equipment	XXXXXX							
5.	Installation of Model		XXX						
6.	Data Collection from Model		XXX	XXXXXX	XXX				
7.	Data Evaluation				XXX				
8.	Data Collection					XXXXXX	XXXXXX		
9.	Analysis of Data				XXXXXX			XXXXXX	
10.	Design Recommendations						XXXXXX	XXXXXX	
11.	Prototype Structures			XXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX
12.	Publicize Results			XXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX
13.	Prototype Assessment							XXXXXX	XXXXXX
14.	Final Report								XXXXXX

X = one month

3.1 Project Proposal Budget Summary

		Year I		Recurring	
		CE	ARS	CE	ARS
4.1	Salaries				
	Professional				
	Project Manager				
	Principal Investigator		3,000		3,000
	Associate Investigator		2,000		1,700
	Other Personnel				
	Technician	2,000		3,000	
	Labor	3,000		3,000	
	Secretary	1,000		1,000	
	Graduate Student	3,000		6,000	
	Total Salaries	10,400	5,000	13,400	4,000
4.2	Staff Benefits	1,500	500	2,000	500
4.3	Total Salaries plus Benefits	11,900	5,500	15,400	5,400
4.4	Equipment	9,000	2,000	4,000	1,000
4.5	Materials and Supplies	5,000	1,000	2,000	500
4.6	Travel		500	1,000	
4.7	Publication & Similar Type Costs			500	
4.8	Computer Costs				
4.9	Miscellaneous Costs				
4.10	Total Costs Other than Salaries (4.4-4.9)	14,000	3,500	7,500	1,500
4.11	Total Direct Costs (4.3 + 4.10)	25,900	9,000	22,900	6,900
4.12	Sedimentation Laboratory Overhead	1,000	1,000	3,100	2,000
4.13	Subcontract Overhead	3,100		4,000	
4.14	Subtotal	30,000	10,500	29,000	8,000
4.15	ARS Overhead 10%	5,400	10,300	34,200	10,500

Project 20308-89

COMPUTATIONAL MODELING OF WATER AND SEDIMENT YIELD FROM AGRICULTURAL WATERSHEDS AS RELATED TO STREAM STABILITY

Personnel Involved: C. V. Alonso, D. G. DeCoursey, S. N. Prasad, and G. C. Bolton

Specific Objectives:

The overall project objective is to devise an improved method for predicting changes in water yield, erosion losses, and channel stability that might be expected as a result of changes in upland watershed management practices. (20308-81)

In developing a validated prediction model, the following specific objectives will be considered:

1. Estimate the amount of soil loss from specified soil-source units with homogeneous characteristics.

2. Estimate the amount of water and sediment transported out of the watersheds through the principal drainage networks.

3. Estimate the rate of channel aggradation and degradation along the flow system.

The model will be oriented towards the needs of the Corps of Engineers for better means of assessing the impact of land-management practices on stream channel behavior within the Yazoo Basin. It will also serve to identify components of the hydrologic cycle needed for model formulation and to indicate research gaps where existing information is inadequate.

Expanded Statement of Problem:

Alluvial streams are dynamic systems that continuously change their configuration and state in response to either changes in the natural environment, or perturbations introduced by man's activity. Frequently, these changes conduce to alteration of the stream-channel stability, which often results in channel migration and shoaling.

Among the leading causes of channel instability there are several that are intimately associated with land-management and conservation practices carried out on the upland areas. They are (a) clearing of land that removes the soil-protective and flow-retardant ground cover, which in turn leads to increased erosion and flood peaks; (b) installation of reservoirs for flood protection and irrigation control, which upset the water-sediment equilibrium downstream of those structures; and (c) excessive soil erosion resulting from uncontrolled sources. The combined effect is an aggregate flow of water and sediment coming from a variety of point and non-point sources within the upstream watersheds.

This aggregate yield acts as a time and space dependent loading on the streams draining the watersheds. If this loading becomes quite different from that which the streams have adjusted to, the result is a breakdown in the stability of the channel system.

The watersheds contributing to the loading of any given channel system exhibit in general a great variety of soils, vegetation, and land uses. In order to effectively assess the impact of these watersheds on the loading of the channel system, it is necessary to develop improved methods for predicting the effects of alternative land managements of those watersheds. There is, therefore, a need for the development of mathematical models so that the hydrology of a watershed can be simulated and the effects of various management practices understood and predicted. Such need was recognized by a recent report of a Joint Task Force of the Southern Region Agricultural Experiment Stations and the USDA (1974). This Task Force divided needed water-related research into several areas. In each of these areas, the need to apply hydrologic models to solve identified problems was given the highest priority.

Because the physical processes governing watershed behavior are very complicated, many past studies have utilized regression models. However, it is difficult to predict the response of a watershed to different land-management activities using regressional methods, because these methods are based on the assumption of time and space invariability. This assumption almost always fails to be valid in the case of natural watersheds.

A second type of models includes lumped parametric simulation methods, such as the TVA Continuous Daily-Streamflow Model (TVA, 1972). These models simulate the response of a given watershed by adjusting a number of coefficients, with little physical significance, using data collected under certain environmental conditions. The impossibility of relating those coefficients to a different set of environmental conditions, seriously restrict the use of these models for predicting the response of ungaged watersheds.

A different class of models embodies the distributed process simulation methods. These techniques use mathematical descriptions of the basic hydrologic processes being modeled, and their interaction. In addition, this approach tends to minimize the number of adjustable parameters and, whenever possible, relates them to physical quantities that can be readily measured in the field. In recognition of the flexibility of this kind of models, and in response to the above mentioned needed for a physically-sound, comprehensive watershed model, the goal of this proposal is the development of an improved process-simulation model consistent with the objectives already enumerated.

Literature Review:

Many hundreds of papers have been written concerning studies on various aspects of hydrology. For this reason it is quite impossible to sum-

marize the previous work that has led to the current understanding of the hydrologic cycle. Reference can be made to some of the existing comprehensive hydrology books (i.e., Chow, 1964), and to a number of American Society of Agronomy Monographs (Luthin, 1957; Van Schilfgaarde, 1974; Hagan, Haise and Edminster, 1967) and reports (Pierre et al., 1966; Nielsen, Jackson, Cary, and Evans, 1972) that discuss current knowledge of soil-water-plant system. Excellent reviews of the progress made during the last five years in several hydrologic subjects have been recently presented by Schaake (1975), Amerman et al. (1975), Johnson and Meyer (1975), and Nordin (1975). Only because of this accumulated knowledge is the proposed project even feasible. As a better understanding of the hydrologic cycle and the basic physical laws governing it have evolved, they have been synthesized into more rational and physically based models. Finally, the accessibility to high-speed digital computers has made possible the development of detailed comprehensive hydrologic models.

The Stanford model (Crawford and Linsley, 1966) was one of the first general models developed to simulate runoff from a watershed. It is basically a lumped-parameter model, although large, heterogeneous watersheds can be subdivided into subwatersheds if sufficient data are available to define model parameters. The model has gained widespread use and as a result has undergone numerous modifications (i.e., Ligon et al., 1969; Claborn and Moore, 1970; National Weather Service, 1972; Ricca, 1974). Holtan and Lopez (1970) have described the USDAHL-70 model of watershed hydrology. Although this model is basically lumped, a watershed can be broken down into smaller homogeneous areas. An attempt is made to incorporate spatial variability by dividing the watershed into land capabilities classes that correspond to uplands, hillslopes, and bottom lands. Dawdy et al. (1970) reported on a lumped-system model similar to the Stanford model which describes surface runoff from small watersheds. TVA (1972) recently described a lumped daily-streamflow model with sixteen parameters, five of which require optimization. This model has been reasonably successful in predicting daily streamflows.

A continuous distributed model is not yet available. However, several single-event distributed models that include part of the hydrologic cycle have been introduced since the pioneering works of Wooding (1965) and Woolhiser and Liggett (1967). Since then, a cascade of various sizes and slopes (Brakensiek, 1967; Kibbler and Woolhiser, 1970) or converging inverted cone-shaped surfaces (Woolhiser, 1969) have been used for geometric representation of complex topographies. The works of these and other investigators have led to the acceptance of the kinematic-wave approximation as an adequate model of shallow overland flow and flow in channels. The reductionist approach to watershed simulation was introduced by Huggins and Monke (1970). They employed a square grid for decomposing a complex watershed into elemental surface units. Most physically-based overland flow models used simplified lumped-system infiltration models. Smith and Woolhiser (1971) were the first to introduce a distributed infiltration model, derived from soil moisture

flow theory, to calculate point infiltration rate, and therefore rainfall excess rate. The foregoing concepts have been incorporated, in one way or another, into more detailed models recently reported by Simons et al. (1975), Smith (1976a, 1976b), and Chery et al. (1976).

Different types of sediment production models have appeared widely dispersed in the technical literature. Reference can be made to a recent review presented by Heinemann and Piest (1975) and to a publication of the Agricultural Research Service (1975). Several regression equations for predicting gross soil erosion have been proposed. The most commonly used among these is the so-called universal soil loss equation (USLE) proposed by Wischmeier and Smith (1965). Other equations of similar nature have been developed by Musgrave (1947), and Gottschalk and Brune (1950). In these equations, the soil loss rate is correlated with storm, land, and vegetation characteristics. Such equations are applicable on seasonal basis or longer. Also, they do not take advantage of the physical processes occurring within the watershed; hence, it is not possible to use them on large, complex watersheds. Williams (1972) modified the USLE to make it applicable for predicting storm sediment yields. Onstad and Foster (1975) combined a different modification of the USLE with the USDAHL-70 watershed model to predict sediment yield for single storms on a watershed basis. They applied their model to two small watersheds with limited success.

The first physically-based sediment yield model was reported by Negev (1967). This model uses the Stanford watershed model for the water phase, and takes into consideration rainfall soil splash, entrainment by overland flow, and rilling and gullying, along with separate channel transport of fine and coarse sediment. Sediment production is evaluated in terms of power functions of water discharge containing a number of parameters that must be calibrated. A modified version of Negev's model has been incorporated in the Agricultural Runoff Management (ARM) model recently reported by Donigian and Crawford (1976). The aforementioned models of Simons et al. (1975) and Smith (1976) incorporate also the capability of describing sediment movement on a watershed as a time and space distributed process. The structures of these two models are similar; however, there are differences in numerical techniques and functional relationships. The sediment movement is described by linking the excess-rainfall flow equations to the sediment continuity equation, with relations describing sediment detachment and transport capacity at any point on the surface or in a channel. So far, these models have been tested in small watersheds with a seemingly degree of accuracy. Curtis (1976) has reported recently a similar model which makes use of the procedure proposed by Meyer and Wischmeier (1969) to describe the movement of soil over land and channel segments. However, this model has not been completely implemented as yet.

Research Approach:

The proposed model will simulate the land-surface hydrologic cycle, sediment production, and water + sediment movement on agricultural watersheds. Conceptually, the model will be divided into overland flow and channel system flow. Different physical processes are important for the two different environments. In the overland flow, processes of interception, evaporation, infiltration and subsurface storage and movement of water, raindrop-impact detachment of soil, erosion, and water + sediment routing to the draining channel network will be simulated. In the channel system, water and sediments contributed by the overland flow will be routed, and the amount of channel erosion and sediment deposition will be determined. In most cases, movement of sediments from watersheds result from the movement of water. For this reason, the sediment yield model will be coupled directly to the water routing model.

Developing a model of this diversity for execution in a digital computer is an elaborate and time-consuming process. In order to reach the objectives of the proposed study within the assigned time table, the effort will be concentrated in selecting the most suitable components of the distributed models mentioned above. These components will be interfaced and modified so as to meet the requirements of this research. Those needed components that are either not sufficiently developed or nonexistent, will be singled out for additional study and development. A preliminary study of the existing models has already disclosed a number of areas that require extensive research and development. They are enumerated in the following.

(a) Current evapotranspiration (ET) models are based on the assumption of a well-watered crop. Obviously, during many periods of the year, the crop is not well watered and ET is limited by the inability of the soil to supply water to the plants at the potential ET rate. Some methods reduce the potential ET as a function of soil dryness. Such simulations normally include some ET-adjusting parameter which, obviously, prevents the use of the model for studying the effects of land management and seasonal variations on the ET rate.

(b) In many areas of the Southeastern United States, precipitation exceeds ET during a considerable part of the year creating a surplus of water. Much of this excess drains vertically and/or horizontally through the soil in the saturated and unsaturated state. This subsurface water movement can be a significant component of the runoff volume. It can also contribute to surface erosion processes due to piping (Jones, 1971), in soil horizons where groundwater flow is concentrated and subject to significant hydraulic gradients. The existing models are very limited in this aspect and there is need for the development of more refined infiltration models along with adequate subsurface water routing components. Some models that will be considered as suitable starting points are those of Smith (1972), Smith and Chery (1973), Freeze (1971), Kipp et al. (1973), and Reisenauer et al. (1974).

(c) A considerable part of the proposed study will be oriented toward improving the existing procedures for the routing of water and sediment.

A preliminary study conducted in cooperation with the University of Mississippi has disclosed the feasibility of obtaining close form solutions for a number of kinematic-wave approximations used in flow routing. The incorporation of such solutions will add significantly to the overall computational efficiency of the model. The use of transitional friction relationships (Morgali, 1970; Woolhiser et al., 1970) will be also investigated. Preliminary tests conducted by Chery et al. (1976) indicate that the response of watershed models with distributed roughness is much more accurate than those with constant roughness. Consideration will also be given to the channel flow routing in those cases where the kinematic-wave approximation breaks down. The accuracy of the current methods used in dynamic-wave simulation of one-dimensional sediment-laden flows (Cunge and Perdreau, 1973; Vreugdenhil and deVries, 1976) will be examined. This should point out which shortcuts can and cannot be taken in carrying out the simulation, and will guide the study towards improved routing techniques.

The sediment routing component will include, out of necessity, simplified representations of the complex processes at work in an agricultural watershed. However, most major sediment processes will be represented, through physically-based models, including: soil detachment by raindrop splash and by overland flow, pick up and transport by surface runoff, interchange of suspended material and bed material in channel flows, amount of scour and aggradation in channel systems, and effects of armoring on bed scouring. To model these processes, a graded material will be represented by a number of discrete particle size fractions. The incorporation of particle size distribution will facilitate the simulation of hydraulic-sorting processes such as bed armoring, or seasonal variations in size distribution of available loose soils. Particular attention will be given to the modeling of soil-transport by overland flow. Current models make little distinction between transport modes in upland flows and in deeper channels. However, Foster and Meyer (1972) have observed significant differences between those two transport conditions.

(d) There is a need to develop specialized models for quantifying sediment sources such as gullies and channel-bank scouring. In developing a model of gully erosion attention will be given to the investigation of the mechanics of gully head cutting and the definition of amount of material supplied by bank caving as a function of climatic events, land characteristics, and changes in base level (Thompson, 1964; Beer and Johnson, 1963).

Channel stability analyses are regularly based on two-dimensional flow models that involve rigid boundary conditions. However, Prasad and Alonso (1976) have shown that the introduction of more realistic mixed-boundary conditons lead to a radical redistribution of unit tractive forces on the channel boundaries. This work, initially developed for

rectangular channels, will be extended to other geometries and flow conditions.

(e) As other critical components of the hydrologic cycle are identified as needing further development, suitable studies will be conducted to provide the needed information. Modular structure of the overall model will be emphasized to facilitate efficient additions and/or modifications to the system. As the predictive components are developed, a prime consideration in choosing the particular model will be the ease of parameter estimation. In order to make the model applicable to simulation of ungaged watersheds, an effort will be made to relate as many parameters as possible to readily measurable watershed characteristics.

References:

Agricultural Research Service, "Present and Prospective Technology for Predicting Sediment Yields and Sources," Proceedings, Sediment-Yield Workshop, Oxford, MS, 1972 (Publication ARS-S-40, 1975, 285 p.)

Amerman, C. R., Klute, A., Skaggs, R. W., and Smith, R. E., "Soil Water," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 451-454.

Beer, C. E., and Johnson, H. P., " Factors Related to Gully Growth in the Deep Loess Area of Western Iowa," Proceedings, 1963 Federal Interagency Sedimentation Conference, USDA Misc. Publ. 970, 1965, pp. 37-43.

Brakensiek, D. L., "A Simulated Watershed Flow System for Hydrograph Prediction: A Kinematic Application," Proceedings, International Hydrology Symposium, Paper No. 3, 1967.

Chow, V. T., Editor, "Handbook of Applied Hydrology," McGraw-Hill Book Co., N. Y., 1964.

Claborn, B. J., and Moore, W. L., "Numerical Simulation of Watershed Hydrology," Technical Report No. HYD14-7001, Dept. of Civil Engineering, The University of Texas at Austin, 1970.

Crawford, N. H., and Linsley, R. K., "Digital Simulation in Hydrology: Stanford Watershed Model IV," Technical Report No. 39, Dept. of Civil Engineering, Stanford University, 1966.

Cunge, J. A., and Perdreau, N., "Mobile Bed Fluvial Mathematical Models," La Houille Blanche, No. 7, 1973, pp. 561-580.

Curtis, D. C., "A Deterministic Urban Storm Water and Sediment Discharge Model," Proceedings, Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, 1976, pp. B58-B69.

Dawdy, D. R., Lichty, R. W., and Bergmann, J. M., "A Rainfall-Runoff Simulation Model for Estimation of Flood Peaks for Small Drainage Basins," USGS Professional Paper No. 506-B, 1972, 28 p.

Donigian, A. S., and Crawford, N. H., "Modeling Pesticides and Nutrients on Agricultural Lands," Report EPA-600/2-76-043, Environmental Protection Agency, 1976, 332 p.

Foster G. R., and Meyer, L. D., "Transport of Soil Particles by Shallow Flow," Transactions, ASAE, Vol. 15, No. 1, 1972, pp. 99-102.

Freeze, R. A., "Three-Dimensional, Transient, Saturated-Unsaturated Flow in a Groundwater Basin," Water Resources Research, Vol. 7, No. 2, 1971, pp. 347-366.

Gottschalk, L. C., and Brune, G. M., "Sediment Design Criteria for the Missouri Basin Loess Hills," Technical Publication No. 97, USDA-SCS, 1950.

Hagan, R. M., Haise, H. R., and Edminster, T. W., Editors, "Irrigation of Agricultural Lands," Monograph 11, American Society of Agronomy, Madison, Wisconsin, 1967.

Heinemann, H. G., and Piest, R. F., "Soil Erosion-Sediment Yield, Research in Progress," Transactions, AGU, Vol. 56, No. 3, 1975, pp. 149-159.

Holtan, H. N., and Lopez, N. C., "USDAHL-70, Model of Watershed Hydrology," Technical Bulletin No. 1435, USDA-ARS, 1971, 84 p.

Huggins, L. F., and Monke, E. J., "A Mathematical Simulation of Hydrologic Events on Ungaged Watersheds," Technical Report 14, Water Resources Research Center, Purdue University, 1970, 46 p.

Johnson, A. I., and Meyer, G., "Groundwater," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 455-458.

Kibler, D. F., and Woolhiser, D. A., "The Kinematic Cascade as a Hydrological Model," Hydrology Paper No. 39, Dept. of Civil Engineering, Colorado State University, 1970.

Kipp, K. L., Cearlock, D. B., Reisenauer, A. E., and Bryan, C. A., "Variable Thickness Transient Groundwater Flow Model-Theory and Numerical Implementation," Report BNWL-1703, Battelle Pacific Northwest Laboratories, 1973.

Ligon, J. T., Law, A. G., and Higgins, D. H., "Evaluation and Application of a Digital Hydrologic Simulation Model," Report No. 12, Water Resources Research Institute, Clemson University, S. C., 1969.

Luthin, J. N., Editor, "Drainage of Agricultural Lands," Monograph VII, American Society of Agronomy, Madison, Wisconsin, 1957.

Meyer, L. D., and Wischmeier, W. H., "Mathematical Simulation of the Process of Soil Erosion by Water," Transactions, ASAE, Vol. 12, No. 6, 1969.

Morgali, J. R., "Laminar and Turbulent Overland Flow Hydrographs," Journal Hydraulics Division, ASCE, Vol. 96, No. HY2, 1970, pp. 441-460.

Musgrave, G. W., "Quantitative Evaluation of Factors in Water Erosion, A First Approximation," Journal Soil and Water Conservation, Vol. 2, No. 3, 1947, pp. 133-138.

National Weather Service, "National Weather Service River System Forecast Procedures," Technical Memorandum NWS HYDRO-14, NOAA, 1972.

Negev, M., "A Sediment Model on a Digital Computer," Technical Report No. 76, Dept. Civil Engineering, Stanford University, 1967.

Nielsen, D. R., Jackson, R. D., Cary, J. W., and Evans, D. D., Editors, "Soil-Water," American Society of Agronomy, Madison, Wisconsin, 1972.

Nordin, C. F., "Erosion and Sedimentation," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 458-460.

Onstad, C. A., and Foster, G. R., "Erosion Modeling on a Watershed," Transactions, ASAE, Vol. 18, No. 2, 1975, pp. 288-292.

Pierre, W. H., et al., Editors, "Plant Environment and Efficient Water Use," American Society of Agronomy, Madison, Wisconsin, 1966.

Prasad, S. N., and Alonso, C. V., "Integral-Equation Analysis of Flows Over Eroding Beds," Proceedings, ASCE Symposium on Inland Waterways for Navigation, Flood Control and Water Diversions, Vol. I, 1976, pp. 760-772.

Reisenauer, A. E., Cearlock, D. B., and Bryan, C. A., "Partially Saturated Transient Groundwater Flow Model-Theory and Numerical Implementation," Report BNWL-1713, Battelle Pacific Northwest Laboratories, 1974.

Ricca, V. T., "The Ohio State University Version of the Stanford Streamflow Simulation Model," Water Resources Center, Ohio State University, 1974.

Schaake, J. C., "Surface Waters," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 445-451.

Simons, D. B., Li, R. M., and Stevens, M. A., "Development of Models for Predicting Water and Sediment Routing and Yield from Storms on Small Watersheds," Report CER74-75DBS-RML-MAS-24, Dept. Civil Engr., Colorado State University, 1975, 130 p.

Smith, R. E., "The Infiltration Envelope: Results from a Theoretical Infiltrometer," Journal of Hydrology, Vol. 17, 1972, pp. 1-21.

Smith, R. E., "Simulating Erosion Dynamics with a Deterministic Distributed Watershed Model," Proceedings, 3rd Federal Interagency Sedimentation Conference, 1976, pp. 163-173.

Smith, R. E., "Field Test of a Distributed Watershed Erosion-Sedimentation Model," Proceedings, National Soil Erosion Conference, Purdue University, 1976.

Smith, R. E., and Chery, D. L., "Rainfall Excess Model from Soil Water Flow Theory," Journal Hydraulics Division, ASCE, Vol. 99, No. HY9, 1973, pp. 1337-1351.

Smith, R. E., and Woolhiser, D. A., "Overland Flow on an Infiltrating Surface," Water Resources Research, Vol. 7, No. 4, 1971, pp. 899-913.

Tennessee Valley Authority, "Upper Bear Creek Experimental Project, A Continuous Daily Streamflow Model," Research Paper No. 8, TVA, 1972.

Thompson, J. R., "Quantitative Effect of Watershed Variables on the Rate of Gully Head Advancement," Transactions, ASAE, Vol. 7, No. 1, 1964, pp. 54-55.

Van Shilfgaarde, J., Editor, "Drainage for Agriculture," Monograph 17, American Society of Agronomy, Madison, Wisconsin, 1974.

Vreugdenhil, C. B., and deVries, M., Discussion of "Mathematical Modeling of Alluvial Channels," by Chen, Y. H., and Simons, D. B., Journal Waterways Harbors and Coastal Engineering Division, ASCE, Vol. 102, No. WW4, 1976, pp. 473-476.

Williams, J. R., "Sediment Yield Prediction with Universal Equation Using Runoff Energy Factor," Proceedings, Sediment-Yield Workshop, Oxford, MS, 1972 (USDA-ARS Publication ARS-S-40, 1975, pp. 244-252).

Wischmeier, W. H., and Smith, D. D., "Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains," Handbook No. 282, USDA-ARS, 1965.

Wooding, R. A., "A Hydraulic Model for the Catchment-Stream Problem, 1, Kinematic-Wave Theory," Journal of Hydrology, Vol. 3, 1965, pp. 254-267.

Woolhiser, D. A., "Overland Flow on a Converging Surface," Transactions, ASAE, Vol. 12, No. 4, 1969, pp. 460-462.

Woolhiser, D. A., Hanson, C. L., and Kuhlman, A. R., "Overland Flow on Rangeland Watersheds," Journal of Hydrology, Vol. 9, No. 2, 1970, pp. 336-356.

Woolhiser, D. A., and Liggett, J. A., "Unsteady, One-Dimensional Flow Over a Plane-The Rising Hydrograph," Water Resources Research, Vol. 3, No. 3, 1967, pp. 753-771.

Table 1. Schedule of Project Activities

	Months since Project Approval							
	6	12	18	24	30	36	42	48
1. Assembly of Suitable Existing Model Components	XXXX	XXXX						
2. Evaluation of Data from Field Sites	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
3. Testing of Existing Model Capabilities	XXXX	XXXX						
4. Development & Interfacing of both New & Improved Model Components		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
5. Development of Procedures for Model Parameter Estimation		XXXX	XXXX	XXXX				
6. Testing of Overall Model Capabilities			XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
7. Simulation of Surface, Subsurface & Channel Processes during Steady & Transient Land-Use Activities						XXXX	XXXX	XXXX
8. Publication of Results		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
9. Final Report							XXXX	XXXX

7.1 Project Proposal Budget Summary

		Year I CE	Year I ARS	Year II CE	Year II ARS	Year III CE	Year III ARS	Year IV CE	Year IV ARS
4.1	Salaries								
	Professional								
	Project Manager								
	Principal Investigators		15,800		25,100		26,100		27,100
	Associate Investigators	12,000		25,500		25,500		25,500	
	Other Personnel								
	Technician		1,000		1,100		1,100		1,200
	Labor								
	Secretary		500		500		600		600
	Graduate Student								
	Total Salaries	12,000	17,300	25,500	26,700	25,500	27,800	25,500	28,900
4.2	Staff Benefits	1,800	1,700	3,800	2,700	3,800	2,800	3,800	2,900
4.3	Total Salaries plus Benefits	13,800	19,000	29,300	29,400	29,300	30,600	29,300	31,800
4.4	Equipment	3,000							
4.5	Materials and Supplies	9,000							
4.6	Travel	2,500		1,000	500	1,000	500	1,000	500
4.7	Publication & Similar Type Costs		500	500	500		500	500	500
4.8	Computer Costs								
4.9	Miscellaneous Costs	500		300		300		300	
4.10	Total Costs Other than Salaries (4.4-4.9)	15,000	500	1,300	1,000	1,300	1,000	1,300	1,000
4.11	Total Direct Costs (4.3 + 4.10)	28,800	19,500	30,600	30,400	30,600	31,600	30,600	32,800
4.12	Sedimentation Laboratory Overhead	1,300	4,200	3,900	6,500	3,900	6,900	3,900	7,100
4.13	Subcontract Overhead	3,600		7,700		7,700		7,700	
4.14	Subtotal	33,700	23,700	42,200	36,900	42,200	38,500	42,200	39,900
4.15	ARS Overhead 18%	6,300	4,300	7,800	6,800	7,800	7,100	7,800	7,300
4.16	Total	40,000	28,000	50,000	43,700	50,000	45,600	50,000	47,200

Project 20808-30

ENTRAINMENT, TRANSPORT, AND ENERGY DISSIPATION IN ALLUVIAL CHANNELS

General Objectives:

1. To investigate and define the stochastic character of sediment entraining boundary shear forces as they are caused by turbulent flow of the type found in natural channels (20808-31).

2. To investigate under controlled conditions the sediment transport rates that are found in large-scale field channels (20808-32).

3. To provide a base of alluvial channel flow resistance data for conditions of unsteady nonuniform flow like those found in natural alluvial channels (20808-33).

Summary of Problem Areas:

Alluvial streams are continually changing their position and shape in response to the hydraulic forces exerted by flowing water on their beds and banks. The boundaries of alluvial streams are composed of particles ranging in size from boulders and cobbles down to silt and clay, and these particles are moved by the hydraulic forces, disturbing the stability of the stream. The lack of knowledge of the magnitude and the mode of application of hydraulic forces to streambed particles has hindered the development of reliable methods of channel stability analysis. Conventional methods ignore the inherently random nature of the hydraulic forces and disregard altogether the significant influence that boundary seepage and secondary currents have on the stability of stream channels. The objective of the present study is to remedy this defect by gathering consistent, complete experimental information on the probabilistic distribution of the hydraulic forces, and on the manner in which these distributions are influenced by various significant channel flow variables.

The sediment carrying capacity of a river determines that behavior of its various channel reaches. Where capacity is less than sediment input, the channel will fill with sediment, causing flooding. Where capacity is greater than sediment input, the channel will degrade, undercut, and destroy its banks, material from which, enters the stream and causes gross fluctuation in streambed configuration. In either case, land use near the stream is risky, and it is virtually impossible to maintain a permanent navigation channel. These situations are mitigated by procedures ranging from redesign of channels to stable cross section through installation of mats, riprap, and spur dike fields. These procedures demand estimates of the sediment carrying capacity of the stream both before and after modification. The present study will develop the principles of sediment transport in rivers as they apply specifically to riverbed materials that will be encountered in the field studies undertaken in the Section 32 Program of the 1974 Streambank

Erosion and Control Evaluation and Demonstration Act, and will be extended to a range of flow variables typical of that encountered in different streams.

Because of seasonal or other variations in rainfall, rivers suffer transient flow conditions, that is, changes in flow with time. A river tries to respond to a transient flow event by adjusting the roughness and slope (the flow resistance) of its bed to conserve energy. This causes the frequent changes in flow depth that make it difficult for engineers designing bank protection to determine how high up on a channel bank the protection will be needed. To predict expected flow depths for design purposes, one first has to predict how a river bed changes its flow resistance during transient flow. At present, engineers do not know how to do this, so they make guesses based on past experiences. The present study is being done to provide rules describing how river beds act during transient flows. The study must be done in a laboratory flume because field studies do not allow the influence of each important variable, such as rate of change of flow velocity and rate of change of flow depth, to be observed separately to give a clear picture of what happens. The laboratory results can be used directly on real rivers by formulating them according to certain laws of similitude that are already known.

Section 1: Entrainment of Streambed Particles by Turbulent Surface Flows (20808-31)

Personnel Involved: C. V. Alonso, K. F. Wylie, and N. L. Coleman

Specific Objectives:

The lack of consistent, complete experimental data on the distribution of hydrodynamic forces acting on streambed particles has hindered the development of a reliable entrainment model. Moreover, implicit in the conventional deterministic approaches is an unrealistic concept of equilibrium since they neglect altogether the intrinsic random nature of these forces. Recent improvements in the understanding of the bed entrainment process, and the development of reliable procedures for measuring and analyzing random data, have opened up a more realistic approach to the analysis of bed material entrainment. Measurements of statistical properties of the instantaneous, point, boundary tractive forces coupled with the postulation of an appropriate stochastic model of sediment entrainment offer a better method for evaluating the equilibrium of streambeds. The proposed research project is designed to evaluate, experimentally, the parameters that would be required by such stochastic models. In order to accomplish this goal, experimental information must be obtained to complement and expand related data already gathered by previous investigators. With this requirement in mind the following experimental objectives have been established:

1. Investigate the cross-sectional variation of the mean values, variance and higher statistical moments of the instantaneous boundary tractive forces in prismatic channels.

2. Investigate the influence of secondary flows on the statistical moments of the instantaneous boundary forces in terms of both channel geometry and flow characteristics.

Specific Problem:

The beds of streams are composed of aggregates, the component particles of which can range in size from boulders and cobbles down to silt and clay. These streambed particles experience forces that are exerted on them by flowing water, and which tend to set them in motion, thus disturbing the stability of the streambed. This is the source of erosion in natural channels, and of damage to canals and irrigation ditches. Knowledge of those forces acting on the streambed is essential for the proper design of a stable channel cross section.

Over the years several analytical models have been postulated for estimating the spatial variation of the mean values of the boundary shear stresses in prismatic channels (Olson and Florey, 1952; Lundgren and Jonsson, 1964). In general, these models are in poor agreement with field observations. The lack of agreement stems in part from postulating the existence of a velocity distribution without secondary flow

throughout the cross section, thus ignoring the effect of secondary currents. However, actual velocity measurments made in rectangular, trapezoidal, and triangular channels have shown that secondary current has a significant influence on the cross-sectional velocity distribution. The above disagreement also arises from ignoring the influence of bank resistance and the turbulent nature of the streamflow. Most of the existing tractive-force models are based on the estimation of a time average boundary shear stress which is generally related to the gross-flow parameters. These models usually involve gross simplifications and, what is even more serious, disregard altogether the dependence of bed-particle stability upon the instantaneous values of the hydrodynamic forces and the probabilistic distributions of these values. In turbulent flows such forces are not constant but are dependent on the local turbulent velocity field, and will vary with time at frequencies of the same order as the turbulent velocities. Raudkivi (1963) observed that entrainment of bed material can take place at values of time-averaged shear stress well below the value of critical stress defined by Shields' function. This observation can also be interpreted to indicate that different entrainment rates can be expected for bed shear stress distributions with different variances but equal mean values. This illustrates the limitation of stability analyses which characterize streambed forces with the ensembled average of statistically distributed forces.

Thus, it is obvious that there is an urgent need for consistent, complete data about the spatial and probabilistic distribution of the hydrodynamic forces acting on erodible channel boundaries. Acquisition of these data will facilitiate the development of more realistic and accurate models of sediment entrainment.

Literature Review and References:

The action of turbulent velocity fluctuations in producing intermittent periods of high boundary stress that initiate movement of streambed particles has been recognized for quite some time (White, 1940; Kalinske, 1943). Extensive flume observations conducted by Vanoni (1964) established that such point boundary forces do indeed produce intermittent bursts of bed material movement. He related this effect to quasiperiodic disruptions of the laminar sublayer as described by Einstein and Li (1956). With the development of adequate flow visualization techniques for investigating the turbulent structure of boundary layers (Kline et al., 1967; Corino and Brodkey, 1969) the description of such quasiperiodic disruptions has been greatly refined. The current consensus is to refer to these intermittent events collectively as manifestations of the bursting phenomenon or the burst-sweep cycle. The history and present status of these developments have been reviewed by Offen and Kline (1973, 1975). In general, the term burst refers to the ejection of a slowly moving parcel of fluid away from the near-wall layer while an inrush of high-speed fluid from the outer layer is called a sweep. This process is a common feature or turbulent shear flows irrespective of boundary-roughness conditions (Grass, 1971). Conditional sampling by Willmarth

and Lu (1972) has shown that during the bursting process very large values of instantaneous Reynolds stresses exist very close to the wall. In summary, it is clear from this brief survey that there are grounds for postulating a direct causal relationship between the bursting phenomenon and the intermittent entrainment of bed particles. Such relationship has been recognized by Sutherland (1967) and quite convincingly demonstrated experimentally by Grass (1970, 1971).

One essential aspect missing in the above investigations is considerations of the effect of secondary flows on the boundary forces. The existence of secondary currents in prismatic conduits has been studied rather extensively (Einstein and Li, 1958; Hoagland, 1960; Liggett et al., 1965; Tracy, 1965). Secondary circulation, concentrated near the corner of the boundary, has a significant effect on the stability of straight alluvial channels (Shen and Komura, 1968). Detailed investigations on the mean shear distribution in corners are reported by Leutheusser (1963) and Liggett et al. (1965). It was shown that the turbulent shear distribution has a greater uniformity than the laminar one. The more even shear distribution can be explained by the existence of secondary currents. Using a Preston-tube technique Ippen et al. (1962) measured the peripheral distribution of mean boundary shear stresses in a trapezoidal channel. Similar measurements were reported by Kartha and Leutheusser (1970) for straight rectangular channels. However, the preceding results are questionable, since the Preston tube is calibrated using a two-dimensional velocity distribution and, furthermore, it has been shown to be insensitive to alignment with respect to the mean flow up to twenty degrees. Better angle-sensitive devices are to be used, such as flush surface hot-film sensors. They are sensitive to small changes of angle of attack and, in addition, can measure point, instantaneous, boundary shear stresses. Hence, these sensors are much better suited to study the interrelationship between secondary currents and the structure of instantaneous boundary stresses.

Alonso, C. V., Klaus, W. H., and Wylie, K. F., "Turbulent Characteristics of Drag-Reducing Flows," Journal Hydraulics Research, Vol. 14, No. 2, 1976, pp. 103-118.

Corino, E. R., and Brodkey, R. S., "A Visual Investigation of the Wall Region in Turbulent Flow," J. Fluid Mech., Vol. 37, 1969, pp. 1-30.

Einstein, H. A., and Li, H., "The Viscous Sublayer Along a Smooth Boundary," J. Eng. Mech. Div., ASCE, Vol. 82, 1956, pp. 945-1-945-27.

Grass, A. J., "Initial Instability of Fine Bed Sand," J. Hydr. Div., ASCE, Vol. 96, No. HY3, 1970, pp. 619-632.

Grass, A. J., "Structural Features of turbulent Flow over Smooth and Rough Boundaries," J. Fluid Mech., Vol. 50, 1971, pp. 233-255.

Hoagland, L. C., "Fully Developed Turbulent Flow in Straight Rectangular Ducts-Secondary Flow, Its Cause and Effect on the Primary Flow, Ph.D. Thesis, MIT, 1960.

Ippen, A. T., and Drinker, P. A., "Boundary Shear Stresses in Curved Trapezoidal Channels," Journal Hydraulics Division, ASCE, Vol. 88, No. HY5, 1962, pp. 143-180.

Kalinske, A. A., "Turbulence and the Transport of Sand and Silt by Wind," Ann. N. Y. Acad. Sci., Vol. 44, 1943, pp. 41-54.

Kartha, V. C., and Leutheusser, H. J., "Distribution of Tractive Force in Open Channels," Journal Hydraulics Division, ASCE, Vol. 96, No. HY7, 1970, pp. 1469-1483.

Kline, S. J., Reynolds, W. C., Schraub, F. A., and Runstadler, P. W., "The Structure of Turbulent Boundary Layers," J. Fluid Mech., Vol. 30, 1967, pp. 741-773.

Leutheusser, H. J., "Turbulent Flow in Rectangular Ducts, Journal Hydraulics Division, ASCE, Vol. 89, No. HY3, 1963, pp. 1-29.

Liggett, J. A., Chiu, C. L., and Miao, L. S., "Secondary Currents in a Corner," Journal Hydraulics Division, ASCE, Vol. 91, No. HY6, 1965, pp. 99-118.

Lundgren, H., and Jonsson, I. G., "Shear and Velocity Distribution in Shallow Channels," Journal Hydraulics Division, ASCE, Vol. 90, No. HY1, 1964, pp. 1-22.

Offen, G. R., and Kline, S. J., "Experiments on the Velocity Characteristics of 'Bursts' and on the Interactions Between the Inner and Outer Regions of a Turbulent Boundary Layer," Stanford Uni. Rep. MD-31, 1973, 230 pp.

Olson, O. J., and Florey, Q. L., "Sedimentation Studies in Open Channels-Boundary Shear and Velocity Distribution by Membrane Analogy, Analytical and Finite Difference Methods," Lab. Report No. sp 34, U. S. Bureau of Reclamation, 1952.

Raudkivi, A. J., "Study of Sediment Ripple Formation," Proc. ASCE, Vol. 89, No. HY6, 1963, pp. 15-33.

Shen, H. W., and Komura, S., "Meandering Tendencies in Straight Alluvial Channels," Journal Hydraulics Division, ASCE, Vol. 94, No. HY4, 1968.

Sutherland, A. J., "Proposed Mechanism for Sediment Entrainment by Turbulent Flows," J. Geophys. Res., Vol. 72, 1967, pp. 6183-6194.

Tracy, H. J., "Turbulent Flow in a Three-Dimensional Channel," Journal Hydraulics Division, ASCE, Vol. 91, No. HY6, 1965, pp. 9-36.

Vanoni, V. A., "Measurements of Critical Shear Stress for Entraining Fine Sediments in a Boundary Layer," Calif. Inst. Tech. Rep. KH-R, 7, 1964.

White, C. M., "The Equilibrium of Grains on the Bed of a Stream," Proc. Royal Soc. Lond., Vol. 174, 1940, pp. 322-338.

Willmarth, W. W., and Lu, S. S., "The Structure of Reynolds Stresses Near the Wall," J. Fluid Mech., Vol. 55, 1972, pp. 65-92.

Research Approach:

The proposed study will consist of an experimental investigation of the spatial and statistical distribution of point boundary forces in prismatic channels. The manner in which those distributions are affected by secondary currents will be also investigated.

The study will be conducted in an existing adjustable slope recirculating flume. The working length of the flume is approximately 18 meters which insures uniform flow conditions. The channel has a rectangular cross-section 60 cm wide and 30 cm deep. The flume has all parts in contact with water made of stainless steel, and is provided with systems for control of water quality and temperature, which are indispensable in hot-film anemometry measurements. The flume is capable of providing a wide range of flow conditions. Through the use of flow straighteners and grids large scale turbulence is suppressed, thus affording a correct background of boundary generated turbulence. A 14-meter long and 10-centimeter diameter smooth pipe has been installed in parallel with the channel for calibration of flush-mounted hot-film probes. Other existing equipment to be used include constant-temperature anemometer systems and FM-instrumentation tape recorders.

Detailed and systematic surveys of the statistical moments of point, instantaneous, shear stresses will be made, over the channel cross-sectional periphery. The shear stresses will be measured with flush-mounted hot-film sensors driven by constant-temperature anemometers, already used by Alonso et al. (1976) in a previous study of turbulent flows. Simultaneously, cross-sectional surveys of the mean longitudinal velocity will be carried out for every flow condition. From these data, the boundary-force process in turbulent flows and its interrelationship with the secondary currents will be assessed. Due to the expected high level of turbulence, the output of the sensors will be directly digitized to avoid the use of first order approximations in converting the outputs into physical units. This procedure eliminates noise and other electronic uncertainties associated with analog converting equipment. The necessary computer software will be expanded from existing programs.

Table 1. Schedule of Project Activities

```
                                           Months since Project Approval
                                  6    12    18    24    30    36    42    48

1. Design of Experiments          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
2. Purchase of Equipment          XXXXXX
3. Computer Software Development  XXXXXX
4. Data Collection                   XXXXXXXXXXXX  XXXXXXXXXXX  XXXXXXXXXXXX
5. Data Evaluation                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
6. Publication of Results                  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
7. Final Report                                                        XXXXXX
```

X = one month

6.1 Project Proposal Budget Summary

		Year I CE	Year I ARS	Year II CE	Year II ARS	Year III CE	Year III ARS	Year IV CE	Year IV ARS
4.1	Salaries								
	Professional								
	Project Manager		5,000		8,000		8,200		8,400
	Principal Investigator		2,000		3,100		3,300		3,400
	Associate Investigator	10,500		10,500		10,500		10,500	
	Other Personnel								
	Technician		1,000		1,100		1,100		1,200
	Labor								
	Secretary		500		500		600		600
	Graduate Student								
	Total Salaries	10,500	8,500	10,500	12,700	10,500	13,200	10,500	13,600
4.2	Staff Benefits	1,600	900	1,600	1,300	1,600	1,300	1,600	1,400
4.3	Total Salaries plus Benefits	12,100	9,400	12,100	14,000	12,100	14,500	12,100	15,000
4.4	Equipment	500							
4.5	Materials and Supplies	400							
4.6	Travel		500		600		600		600
4.7	Publication & Similar Type Costs		500		500		500		500
4.8	Computer Costs								
4.9	Miscellaneous Costs								
4.10	Total Costs Other than Salaries (4.4-4.9)	900	1,000		1,100		1,100		1,100
4.11	Total Direct Costs (4.3 + 4.10)	13,000	10,400	12,100	15,100	12,100	15,600	12,100	16,100
4.12	Sedimentation Laboratory Overhead	700	2,200	1,600	3,200	1,600	3,400	1,600	3,500
4.13	Subcontract Overhead	3,200		3,200		3,200		3,200	
4.14	Subtotal	16,900	12,600	16,900	18,300	16,900	19,000	16,900	19,600
4.15	ARS Overhead 18%	3,100	2,300	3,100	3,300	3,100	3,500	3,100	3,600
4.16	Total	20,000	14,900	20,000	21,600	20,000	22,500	20,000	23,200

Section 2: Large-Scale Flume Study of the Transport of Bed Material from a Natural Stream (20003-32)

Personnel Involved: Joe C. Willis

Specific Objectives:

In connection with the program goal of providing a data base for the analysis of channel rectifications, this project seeks to accomplish the following specific objectives:

1. To equip the 250-ft test channel at the USDA Sedimentation Laboratory to obtain total load, suspended load, and bed profile measurements, along with measurements of pertinent hydraulic characteristics.

2. To obtain data from flume tests to relate te sediment transport rate and bed-form properties to the hydraulic characteristics of alluvial channel flow.

3. To use the data in testing existing relationships and/or developing new relationships for transport and bed roughness in alluvial channels.

4. To verify the chosen relationships by comparison of predictions and field measurements.

Specific Problem:

In routing the sediment and water through the channel network of a watershed, relationships between the transport capacity of a flow and predictable flow variables are required. These relationships are especially crucial in the redesign of channels to stable cross sections. Along with the continuity equation for the sediment, accurate transport relationships would permit the transport, deposition, and erosion quantities to be predicted. Unfortunately, no adequately verified transport relationship is available today for use in the design procedures. A particular relationship may be satisfactory for the bed material and flow conditions in a particular channel, but it may give completely unreliable results for others. Thus in development of models for a new watershed and channel system, verification of existing transport relationships and/or development of new, more reliable relationships is necessary.

A related problem is encountered in routing the runoff through the channel system. Not only does the flow specify its own transport capacity, but also the bed forms that result from this transport impart a wide range of friction factors and influence the hydraulic characteristics of the flow. Flow routing techniques that fail to account for changes in bed roughness may give erroneous results especially in the use of predicted flow variables to determine the transport rate. Yet, no resistance relationship that may be used with confidence is now available.

In view of the uncertainties associated with transport and bed roughness and the absence of a sound theoretical base for describing these phenomena, one is forced to resort to experimental data to verify existing descriptions or to develop new relationships. Field data are vital for this verification, but field channels each exhibit a limited set of flow variables dictated by its bed material and flow rating curve. For development of models with general applicability, verification for an extended range of flow conditions is desirable.

Literature Review and References:

Numerous relationships have been proposed for relating the sediment transport rate to flow and sediment variables. Comprehensive reviews of those that have been available for a number of years were presented by Shulits (1969) and by the ASCE Task Committee (1971b). A review of resistance relationships applicable to alluvial channel flow was presented by the ASCE Task Committee (1971a). The reviews presented in the above references are quite good and they point out the limitations of the various relationships that are included.

In recent years, work at the Sedimentation Laboratory has sought more reliable transport models based on the principles of the mechanics of sediment transportation and from similitude relationships derived from the equations of motion for the flow of a sediment-water mixture over an alluvial bed.

Use of all available flume transport data for equilibrium flows defined a relationship between a dimensionless sand load and the Froude number and a grain-diameter similitude number (Willis and Coleman, 1969). This relationship was formulated into a transport model (Willis, 1974) that can be readily incorporated into a routing procedure, but verification is necessary to access its applicability to particular field situations.

The sediment load is generally assumed to be transported by two mechanisms--suspension by turbulent eddies and bed-load transport of the particles in contact with the bed by the drag forces of the flow. The mechanics of sediment suspension is fairly well defined. Several models have been proposed to describe the concentration distribution over the flow depth (Rouse, 1937; Vanoni, 1944; Zagustin, 1968; Coleman, 1969; Willis, 1969) and all of these seem to reliably approximate observed distributions over much of the flow depth. The integral, over the flow depth, of the product of velocity and concentration, defines the suspended load. This integral is divergent for the models except that of Willis (1969) unless a lower limit of integration is used. An appropriate lower limit for the Willis model gave good agreement between predicted and observed suspended loads in a flume channel.

A bed-load prediction method has been derived by superimposing the loads contributed by each Fourier frequency component of temporal records of bed elevation (Willis, 1976). In the absence of actual records of bed elevations, the experimental data from a small flume channel suggests a

relation between the dune load's contribution to the mean discharge concentration and the Froude number. The sum of this dune load and the suspended load served as a good estimate of the measured total load for the flume tests.

The foregoing techniques for estimating the sediment load offer considerable promise. They are based more closely on the actual mechanics of sediment transportation than are hitherto available formulations. However, adequate verification for large test channels and field channels has not been accomplished.

References:

Task Committee on Preparation of Sedimentation Manual, 1971b, "Sediment Discharge Formulas", J. Hydraulics Div., ASCE, Vol. 97, No. HY4, pp. 523-567.

Task Committee on Preparation of Sedimentation Manual, 1971a, "Hydraulic Relations for Alluvial Streams", J. Hydraulics Div., ASCE, Vol. 97, No. HY1, pp. 101-141.

Shulits, Sam, and Hill, Ralph D., Jr., 1968, "Bedload Formulas", Hydraulics Laboratory Bul., Penn. State Univ., 153 p.

Willis, Joe C. and Coleman, Neil L., 1969, "Unification of Data on Sediment Transport in Flumes by Similitude Principles", Water Resources Res., Vol. 5, No. 6, pp. 1330-1336.

Rouse, Hunter, 1937, Closure Discussion to "Modern Conceptions of the Mechanics of Fluid Turbulence", Trans. ASCE, Vol. 102, pp. 523-543.

Vanoni, Vito A., 1944, "Transportation of Suspended Sediment by Water", Proc. ASCE, Paper 2267, pp. 793-828.

Coleman, Neil L., 1969, "A New Examination of Sediment Suspension in Open Channels", J. Hydraulic Res., Vol. 7, No. 1, pp. 67-82.

Zagustin, Konstantin, 1968, "Sediment Distribution in Turbulent Flow", J. Hydraulic Res., Vol. 6, No. 2, pp. 163-172.

Willis, Joe C., 1972, "An Error Function Description of the Vertical Suspended Sediment Distribution", Water Resources Res., Vol. 5, No. 6, pp. 1322-1329.

Willis, Joe C., 1972, "A New Mathematical Model for the Velocity Distribution in Turbulent Shear Flow", J. Hydraulic Res., Vol. 10, No. 2, pp. 205-225.

Willis, Joe C., 1976, "Sediment Discharge of Alluvial Streams Calculated from Bed-Form Statistics", Ph.D. Thesis, The University of Iowa, 200 p.

Research Approach:

The sediment discharge relationships that have been proposed may be divided into three groups--empirical transport relationships, similitude relationships, and transport mechanics relationships. The research of this project will investigate and be applicable to each of these groups.

The empirical relationships express the transport rate as a function of mean velocity $\bar{V}$, flow depth y_T, sediment size d and unit volume weight γ_s, fluid properties of unit volume weight γ_w and kinematic viscosity ν, and/or boundary shear stress τ_o or some combination of these variables such as unit stream power. Several formulations of this type are presented in the survey references (Shulits, 1968; ASCE Task Committee, 1971b).

The similitude approach of Willis and Coleman (1969) relates a dimensionless sediment load

$$A_T = G_T/(\gamma_s - \gamma_w)\, \bar{V}\, y_T \qquad (1)$$

to the Froude number of the flow

$$F = \bar{V}/\sqrt{g y_T} \qquad (2)$$

and a grain diameter similitude number

$$D = d\, g^{1/3}/\nu^{2/3}. \qquad (3)$$

In (1) through (3), G_T is the total sediment load in weight per second and unit channel width and g is the gravity constant.

In the transport mechanics approach, the total load G_T is considered to be the sum of the dune load (or bed load) G_d and the suspended load G_s. The dune load has been derived as the sum of the loads contributed by Fourier frequency increments (Willis, 1976) as

$$G_d = \sqrt{s}\, \sigma_T \sum_{f=0}^{f_c} \frac{W(f)\, S(f)\, \Delta f}{s \left(\sum_{f=0}^{f_c} S(f)\, \Delta f \right)^{1/2}} \qquad (4)$$

where σ_T is the total standard deviation of the bed surface, S(f) is the relative power spectral density, Δf is the frequency interval, W(f) is the migration velocity of bed-form Fourier frequency f. The migration velocities are determined from phase angles of the cross spectral density from two records of bed elevation.

The suspended load is given by the integral

$$C_s = \int_{y_o}^{y_T} C_s\, V\, dy \tag{5}$$

where C_s and V are the local concentration and velocity, respectively, at the level y above the mean bed plane. The quantity y_o represents the lower limit of integration which is required for all models of C_s and V. The models proposed by Willis (1969, 1971) are

$$C_s = C_a\, e^{\sigma_s (P - P_a)} \tag{6}$$

and

$$V = \overline{V} - 1.668\, U_*(\Psi_y - 1/\sqrt{\pi})/k \tag{7}$$

where C_a is the reference concentration at a distance "a" above the mean bed plane and σ_s is the suspension exponent defined by

$$\sigma_s = -1.67\, W/k\, U_* \tag{8}$$

with W denoting the fall velocity of the sediment particles, U_* the shear velocity $(\tau_o g/\gamma_w)$, and k is analogous to the Karman constant and has a value of about 0.33 for open channel flow. The quantity P is a normalized depth variable obtained from

$$y/y_T = (1/\sqrt{2\pi}) \int_{-\infty}^{P} e^{n^2/2}\, dn \tag{9}$$

The quantity Ψ_y denotes a group of terms:

$$\Psi_y = (1/\sqrt{2\pi})\, e^{-P^2/2} - P(1 - y/y_T) \tag{10}$$

With γ_b denoting the bulk unit weight of the bed matcial and $CDF(a/y_T)$ the cumulative distribution function of the bed elevations, the following expression for C_a:

$$C_a = \gamma_b\, [1 - CDF(a/y_T)] \tag{11}$$

gave a reliable estimate of the suspended load for tests in a small flume (Willis, 1976).

Verification of the foregoing transport relationships for the flows and bed material of a natural channel requires experimental data that include actual measurements of the transport quantity. These measurements are often difficult to obtain in field channels and will probably be available for only one section of a stream channel of an instrumented watershed. The range of such measurements will be limited by the occurrence of flood events and the depth-discharge relation for the section.

In order to develop a model of general applicability, controlled experiments in a laboratory flume can extend the measurements to a much wider range of dimensionless variables and avoid the dependence on flood events. The 250-ft test channel at the Sedimentation Laboratory offers a discharge range (160 cfs) that exceeds that of other recirculating flumes by a factor of almost 10. At these high flow rates (high Reynolds numbers) the similitude uncertainties of smaller flows are minimized. Use of this facility with bed material from the main channel of a highly instrumented watershed is envisioned in this project.

The 250-ft flume will be used to obtain accurate measurements of the total sediment load as well as measurement of the bed profile and flow variables that are considered by the available models to control the transport rate. In addition to the gross flow and transport measurements, samples and flow velocity measurements will be obtained over the flow depth to define the concentration and velocity distributions. Spatial and temporal records of bed elevation will be obtained from ultrasonic distance meters to provide a measure of the dune or bed load.

Insofar as possible, the flume data will be compared with measurements from field channels to ascertain the agreement between model and prototype. For moderately long flow events temporal records of bed elevation could be obtained from a fixed bridge section with negligible flow constriction. Whereas point samples and velocity measurements over the flow depth may be difficult to obtain in the field, integrated suspended loads could be obtained for about the upper 90% of the flow depth for comparison with equivalent integrals from the suspension models. The availability of at least one weir for total load measurements in the field as part of another project is assumed.

Equipment Needs:

1. 10 each pressure transducers for water surface piezometers - including a 10-channel carrier-demodulator modified to provide full-scale zero suppression (switch selectable).

2. 3 each differential transducers for elbow flow meters - including 3-channel carrier demodulator.

3. 3 each density cells for total-load measurements.

4. Magnetic velocity meter.

5. Computer terminal - APDS consol 520.

Table 1. Schedule of Project Activities

		Months since Project Approval: 6 12 18 24 30 36 42 48
1.	Planning	XXXXXXXXXXXX
2.	Literature Review	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
3.	Experimental Design	XXXXXXXX
4.	Equipment Purchase	XXXXXXXXXXX
5.	Installation of Instrumentation	XXXXXXXXXXXX
6.	Procurement & Loading of Bed Material	XX
7.	Preliminary Tests	XXXXXXXXXXX
8.	Debugging & Modification of Experimental Apparatus & Techniques	XXXXXXXXXXX
9.	Primary Test Series	XXXXXXXXXXXXXXX
10.	Supplemental Tests	XXXXXX
11.	Data Analysis	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
12.	Progress Reports	X X X X X X X
13.	Model Formulation	XXXXXXXXXXXXXXXXXXXXXXXXXXX
14.	Model Evaluation	XXXXXXXXXXXXXXXXXXXX
15.	Publication Preparation	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
16.	Results Summary	XXXXXXXXXXXX
17.	Final Report	XXXXXX

X = one month

5.1 Project Proposal Budget Summary

		Year I		Recurring	
		CH	ARS	CH	ARS
4.1	Salaries				
	Professional				
	Project Manager				
	Principal Investigator		8,600		14,700
	Associate Investigator				
	Other Personnel				
	Technician	2,500	600	3,700	1,000
	Labor	800	500		800
	Secretary		600		1,100
	Graduate Student				
	Total Salaries	3,300	10,300	3,700	17,600
4.2	Staff Benefits	500	1,000	500	1,000
4.3	Total Salaries plus Benefits	3,800	11,300	4,200	19,400
4.4	Equipment	21,200			
4.5	Materials and Supplies	1,600	600	1,200	1,000
4.6	Travel		300	600	500
4.7	Publication & Similar Type Costs		300		500
4.8	Computer Costs				
4.9	Miscellaneous Costs	4,800		8,000	
4.10	Total Costs Other than Salaries (4.4-4.9)	27,600	1,200	9,800	2,000
4.11	Total Direct Costs (4.3 + 4.10)	31,400	12,500	14,000	21,400
4.12	Sedimentation Laboratory Overhead	1,300	2,500	1,600	4,300
4.13	Subcontract Overhead	1,100		1,300	
4.14	Subtotal	33,800	15,000	16,900	25,700
4.15	ARS Overhead 18%	6,200	2,700	3,100	4,700
4.16	Total	40,000	17,700	20,000	30,400

Section 3: Alluvial Channel Flow Resistance Under Transient Flow Conditions (20008-33)

Personnel: Principle Investigator: Neil L. Coleman, Supervisory Geologist, Sediment Transport Unit

Associate Investigators: Selected hydraulic engineers from various Research Units will act as associate investigators during the several phases of this project.

Graduate Student: One advanced graduate student from the University of Mississippi or another appropriate institution will be selected to work full-time on this project.

Specific Objectives:

1. To provide a base of alluvial channel flow resistance data for conditions of unsteady nonuniform flow like those found in natural alluvial channels.

2. To provide this data base in terms compatible with mathematical modeling practice as used in flood routing and drainage basin studies with application to evaluation of channel stability.

Specific Problem:

Flow in natural streams consists of a series of floodwaves which cause spatial and temporal variations of depth and mean velocity. The general dynamic equation for such a flood wave is derived from the unsteady flow form of the Bernoulli equation (Chow, 1959) and is:

$$\frac{\partial y}{\partial x} + \frac{U}{g}\frac{\partial U}{\partial x} + \frac{1}{g}\frac{\partial U}{\partial t} + \frac{\partial n}{\partial x} + S_f = 0 \qquad (1)$$

where y is flow depth;
x is horizontal distance along the channel;
U is flow velocity;
g is gravity field strength;
t is time;
is bed elevation above a datum;
and S_f is the energy gradient due to frictional head losses.

In using equation (1) for flood routing or mathematical modeling of streamflow, the frictional effect is usually accounted for by substituting some sort of flow resistance relation for S_f, as, for example,

$$S_f = \frac{U^2}{gy}\frac{f}{8} \qquad (2)$$

in which f is the Darcy-Weisbach resistance coefficient. Equation (1) then becomes:

$$\frac{\partial y}{\partial x} + \frac{U}{g}\frac{\partial U}{\partial x} + \frac{1}{g}\frac{\partial U}{\partial t} + \frac{\partial n}{\partial x} + \frac{U^2}{gy}\frac{f}{8} = 0 \qquad (3)$$

The above procedure rests on the assumption that a resistance relation like equation (2), which is derived only for steady uniform flow, is likewise valid for floodwave flow. Also, in any schemes for integrating equation (3) as a part of a mathematical model for flood routing, it is necessary either to assume a constant value for f, or to assume some sort of model for temporal and spatial variation of f, since all other variables in the equation are functions of x and t. Such models are totally lacking, although field studies of transient floodwave flows (Colby, 1960; Coleman, 1962) have proven that during the passage of a flood wave the resistance to flow in a given channel reach changes substantially with time, apparently in conjunction with changes in the kinds of bed configuration occurring on the bed channel bottom. Because of the obvious coupling of U, y, and bed configuration properties, such field studies have failed to yield the desired general mathematical model for the variation of f.

If means were available for evaluating each term in equation (2) under controlled and uncoupled experimental variations of U and y with t, and if at the same time measurements of various quantitatively defined bed configuration properties could be made, it would be possible to determine the general functional forms of the set of equations comprising a mathematical model for transient flow channel resistance. These equations could then be suitably parameterized and incorporated in flood routing or flow simulation models.

It is proposed to develop an experimental facility, based on an existing 100-ft. recirculating flume, and to carry out the experiments needed to find the transient flow resistance functions postulated above.

Literature Review and References:

Modern efforts to study alluvial channel flow resistance began with the application by Keulegan (1938) of the Nikuradse pipe flow resistance model to steady open channel flow with rigid boundaries. The utility of the Darcy-Weisbach coefficient for open channel application was demonstrated in this work.

Brooks (1958) deeply perturbed workers in fluvial hydraulics by his experimental finding that neither the Chezy nor the Manning nor the Darcy-Weisbach coefficients could be considered constant for a given channel, and that furthermore, they did not vary with flow according to single-valued functions, but according to functions related in some way to the sequential appearance of ripples, dunes, and antidunes on alluvial channel beds. At this point, when the situation in alluvial channels with steady uniform flow appeared so complicated, the feasibility of ever understanding natural channels with transient flows seemed very slight. For a period of time the attention of most hydraulicians was

focused strictly on steady flows. Many methods of predicting alluvial channel resistance coefficients were produced during this period, the most notable being that of Alam, Cheyer, and Kennedy (1966) and that of Engelund (1966). None of the methods are particularly effective for natural alluvial channels with transient flows, although all have a range of conditions for which they are approximately effective.

The practical importance of the time variation of channel resistance was emphasized by the studies of Colby (1960) and Dawdy (1961) of the occurrence of discontinuous rating curves in alluvial channels. This emphasis led to a purely observational study (Coleman, 1962) which defined time trends of the Darcy-Weisbach coefficient during a series of ephemeral runoff events with single peaks which occurred in a selected and instrumented alluvial channel reach. The data from this study has since been subjected to several different analyses in an attempt to find a general mathematical model for the variation of the Darcy-Weisbach coefficient, but no analysis has been successful.

Alam, A. M. A., T. F. Cheyer, and J. F. Kennedy (1966) Friction factors for flow in sand bed channels. Mass. Inst. of Technology, Hydrodynamics Laboratory Rept. No. 78.

Brooks, N. H. (1958) Mechanics of streams with movable beds of fine sands. Trans. ASCE, Vol. 123.

Colby, B. R. (1960) Discontinuous rating curves for Pigeon Roost and Cuffawa Creeks in north Mississippi. USDA-ARS-4-136.

Coleman, N. L. (1962) Observations of resistance coefficients in a natural channel. Pub. No. 59, IASH Commission on Land Erosion, Bari, Italy.

Dawdy, D. R. (1961) Depth-discharge relations of alluvial streams-discontinuous rating curves. USGS Water Supply Paper 1498-C.

Engelund, F. (1966) Hydraulic resistance of alluvial streams. ASCE, Jour. of Hydraulics Div., Vol. 92, HY2.

Research Approach:

Rearrangement of equation (3) gives:

$$f = -8 \frac{gy}{U^2} \frac{\partial y}{\partial x} + \frac{y}{U} \frac{\partial U}{\partial x} + \frac{y}{U^2} \frac{\partial U}{\partial t} + \frac{gy}{U^2} \frac{\partial \eta}{\partial t} \qquad (4)$$

Various schemes are available for differentiating f relative to x and t, and these will form the foundation for obtaining experimentally the functional forms for a set of equations comprising a mathematical model for spatial and temporal variation of f. The analytical approach that will be the most effective cannot be defined more closely until a body

of data is available for evaluating the terms in equation (4) numerically for some specific cases. Thus emphasis will be on data collection according to a general experimental design permitting the evaluation of $\partial y/\partial x$, $\partial U/\partial x$, $\partial U/\partial t$, and $\partial \eta/\partial t$.

Phase I of the project will occupy the remainder of the current fiscal year, and will consist entirely of experimental equipment setup and testing. An existing 100-ft. recirculating flume with discharge capacity up to 18 cfs. and slope adjustability to 1% will be used as the basic facility. The flume will be equipped with a depth and discharge sensing and control system interfaced with existing Sedimentation Laboratory Computer facilities. The system will be designed to provide preprogrammed time variations of (1) flow depth while holding mean velocity constant, (2) velocity while holding flow depth constant, or (3) both flow depth and mean velocity, thus producing a predefined hydrograph. Also provided will be a series of transducers, at regular stations along the flume, which will give instantaneous profiles of the water surface and alluvial bed elevations. All the above equipment will be interfaced with the computer. A means of calculating the various temporal and spatial partial derivatives from the monitored measurements will be devised.

Phase II of the project will consist of a series of steady uniform flow experiments, in which the various control systems installed will be used to maintain close tolerances on experimental conditions, and the data gathering devices will permit the determination of the hydraulic gradients, etc. needed for calculating conventional steady-state values of f under different flow conditions. These experiments will be carried out using a flume bed material typical of the channels to be monitored in the instrumented watersheds that will be operated under other parts of the collaborative USACE and ARS program. The results of these experiments will provide a basic steady-state channel resistance diagram for the alluvial material used in the study. This diagram should show the changes in f with various conditions of flow, and also the concurrent changes in bed configuration regime which all previous work has shown to be significant.

In Phase III, transient mean velocity studies will be carried out at constant flow depths, using selected points on the steady-state resistance diagram as starting points, and observing the changes displayed by the channel as the transient velocity event progresses. Phase IV will consist of similar experiments, but with transient depth events and constant mean velocity. Data from phases III and IV should serve to separate the effects of mean velocity and flow depth, which are coupled in a normal hydrograph flow event, and allow them to be understood independently.

Phase V will consist of experiments in which a hydrograph consisting of preprogrammed simultaneous variations of depth and mean velocity will be imposed on a selected flow situation previously studied during the steady state experimental phase. Observations made during these experi-

ments will be interpreted in the light of information from Phases III and IV to formulate the mathematical model for variaton of f.

Equipment Needs:

5 ea. flow cross section velocity transducers.

5 ea. water surface elevation transducers.

5 ea. bed elevation transducers.

1 ea. water temperature meter.

1 ea. density cell for total load measuring system.

1 ea. flow depth sensing and control system, consisting of water level sensor, and control servomechanics and valves for water supply lines and drain lines.

1 ea. discharge and pump speed sensing and control system, consisting of an existing flow meter and tachometer, and appropriate transducers, relays, and servomechanisms.

1 ea. Minicomputer with CRT terminal, limited memory, control actuator capability, and data acquisition and transmission capability, suitable for interfacing with existing ModComp IV computer.

Table 1. Schedule of Project Activities

	Activity	Months since Project Approval 6	12	18	24	30	36	42	48
1.	Planning								
2.	Literature Review	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXX
3.	Phase I Equipment Setup	XXXXXX	XXXXXX						
4.	Phase II Steady State Studies			XXXXXX					
5.	Phase III Transient Discharge Studies				XXXXXX				
6.	Phase IV Transient Depth Studies					XXXXXX			
7.	Phase V Hydrograph Studies						XXXXXX	XXXX	
8.	Progress Reports				XXXXXX				
9.	Data Analysis				XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXX
10.	Final Report Preparation							XXXXX	XXXXXX

X = one month

3.1 Project Proposal Budget Summary

		Year I		Year II		Year III		Year IV	
		CE	ARS	CE	ARS	CE	ARS	CE	ARS
4.1	Salaries								
	Professional								
	Project Manager								
	Principal Investigator		3,300		12,200		12,900		13,500
	Associate Investigator		3,900		5,500		2,900		9,100
	Other Personnel								
	Technician	3,700		3,700		3,900		2,000	
	Labor		800		300		300		300
	Secretary			1,000		1,100		3,500	
	Graduate Student								
	Total Salaries	3,700	13,500	4,700	18,000	5,000	16,100	5,500	22,900
4.2	Staff Benefits	500	1,400	700	1,800	700	1,600	800	2,300
4.3	Total Salaries plus Benefits	4,200	14,900	5,400	19,800	5,700	17,700	6,300	25,200
4.4	Equipment	51,100		4,000		2,900		2,700	
4.5	Materials and Supplies	20,500		1,000		500		500	
4.6	Travel								
4.7	Publication & Similar Type Costs				1,000	500	1,000	800	1,000
4.8	Computer Costs								
4.9	Miscellaneous Costs								
4.10	Total Costs Other than Salaries (4.4-4.9)	71,600		5,000	1,000	3,900	1,000	4,000	1,000
4.11	Total Direct Costs (4.3 + 4.10)	75,900	14,900	10,400	20,800	9,600	18,700	10,300	26,200
4.12	Sedimentation Laboratory Overhead	3,100	3,200	1,200	4,500	1,200	4,100	1,200	5,600
4.13	Subcontract Overhead	1,100		1,400		1,500		1,600	
4.14	Subtotal	80,000	18,100	13,000	25,300	12,300	22,800	13,100	31,800
4.15	ARS Overhead 18%	14,600	3,300	2,400	4,600	2,300	4,200	2,400	5,800
4.16	Total	94,600	21,400	15,400	29,900	14,600	27,000	15,500	37,600

Project 20808-70

RUNOFF, EROSION, INFILTRATION, AND SEDIMENT CHARACTERISTICS OF SELECTED SOILS AND LAND USES

General Objectives:

1. To evaluate erosion and runoff from typical field conditions that are source areas for major channel systems. (20808-71)

2. To determine changes in the soil water state for selected field areas above major channel systems. (20808-72)

Expanded Statement of the Problem:

Generally, channel stability is most severely threatened by increased flows (runoff) that occur during and immediately following major storm events. The sediment load of the runoff and the physical characteristics of the sediment may also affect channel stability. Such channel flows come largely from numerous source areas throughout the contributing watershed. The amount of surface runoff depends on the absorption characteristics (infiltration, interception) of upland areas and the rate of runoff depends on the hydraulic characteristics of the upland flow system that affect conveyance and detention.

The sediment load of the runoff depends on the erosion rate and on the physical characteristics of the eroded sediment that affect the potential for subsequent deposition of this sediment before it reaches the channel. Most watersheds include numerous different land-use conditions that vary in rates of sediment production and runoff. Knowledge of such rates for various typical watershed conditions provides a basis for determining their impact on channel stability.

The amount of water discharged to the channel system depends on the infiltration capacity of each subcatchment. Infiltration capacity is related to a multitude of factors, especially antecedent soil moisture and surface seal development. By determining changes in the soil water state in selected subcatchments, the gross response of the watershed to incident rainstorm events can be evaluated.

Section 1: Runoff, Erosion, Infiltration, and Sediment Characteristics of Selected Soils and Land Uses ([illegible]-71)

Personnel Involved: Don Meyer, Matt Romkens, William Harmon

Objective:

To rapidly and efficiently obtain data on runoff, erosion, infiltration, and sediment characteristics.

Research Approach:

Unique experimental equipment available at the Sedimentation Laboratory will be used on research plots. This equipment includes:

1. A portable rainfall simulator (rainulator) capable of applying an identical series of intense simulated rainstorms to field plots, whenever or wherever desired. As many as 3 plots, each up to 75 feet long and 14 feet wide, can be tested simultaneously.

2. A smaller interrill-research rainfall simulator capable of applying rainstorms at a wide range of intensities to crop-row sideslopes or land-surface areas where raindrop impact is the primary erosive agent. Because of the smaller-sized plots and lesser water requirements, this equipment has the potential for testing a wider range of soils, crops, tillage systems, etc. than the rainulator.

3. A laboratory rainfall simulator, similar to the interrill one, for evaluating the effects of slope steepness, land-surface cover, rain intensity, etc. on interrill erosion.

Each of these research tools is used with a wide array of accessory components for obtaining the desired data.

The rainulator will be used to obtain data on several major land uses that are typical on the watershed above the selected channel system, such as (1) pasture, (2) woodland, (3) soybeans, and (4) cotton.

The interrill-research equipment may be used to study these conditions at other rain intensities and/or on other soils, and it may also be available to test other land uses that may be of interest. A series of these interrill units may be used to test methods for routing interrill (row sideslope) runoff and sediment through the field and/or watershed flow system.

The laboratory research equipment will provide supplementary information for interpreting the field data. It will enable certain studies to proceed at times of the year when field research is not appropriate, and it also provides more controlled conditions for research.

Table 1. Schedule of Project Activities

```
                                         Months since Project Approval
                                     6     12    18    24    30    36    42    48

1. Planning                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
2. Equipment Design             XXXXXXXXXXXXXXXXX
3. Equipment Construction       XXXXXXXXXXXXXXXXXXX     XXXXXXX
4. Equipment Testing            XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
5. Rainulator Field Research                     XXXX        XXXX
6. Interrill Field Research                      XXXX        XXXX
7. Field Data Analysis                             XXXXXXXXXXXXXXXXXXXXXX
8. Laboratory Research                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
9. Interpretation of Results                                   XXXXXXXXXXXXXXXXXX

   X = one month
```

3.1 Project Proposal Budget Summary

		Year I CE	Year I ARS	Year II CE	Year II ARS	Year III CE	Year III ARS	Year IV CE	Year IV ARS
4.1	Salaries								
	Professional								
	Project Manager								
	Principal Investigator		11,000				12,100		
	Associate Investigator		9,000				10,000		
	Other Personnel								
	Technician	2,000	6,500			11,000	7,100		
	Labor	4,000				4,500			
	Secretary		1,000				1,000		
	Graduate Student								
	Total Salaries	6,000	37,500			15,500	30,200		
4.2	Staff Benefits	800	2,800			2,400	3,000		
4.3	Total Salaries plus Benefits	6,800	40,300			17,900	33,200		
4.4	Equipment	28,000				2,000			
4.5	Materials and Supplies	3,000	3,000			3,000			
4.6	Travel	1,000	1,000				2,000		
4.7	Publication & Similar Type Costs		1,000				1,000		
4.8	Computer Costs								
4.9	Miscellaneous Costs								
4.10	Total Costs Other than Salaries (4.4-4.9)	32,000	5,000			5,000	3,000		
4.11	Total Direct Costs (4.3 + 4.10)	38,900	35,300			22,900	36,200		
4.12	Sedimentation Laboratory Overhead	1,600	2,600			2,100	2,000		
4.13	Subcontract Overhead	2,100				5,400			
4.14	Subtotal	42,600	37,900			30,400	38,200		
4.15	ARS Overhead 18%	7,700	6,700			5,500	7,100		
4.16	Total	50,300	44,000			35,900	45,300		

Section 2: Soil Water State for Study Watersheds (20898-72)

Personnel Involved: Matt Dankens and Frank D. Whisler, Research Associate

Objective:

Determine changes in soil water state for study watersheds.

Research Approach:

The watersheds to be selected (a maximum of three) should be reasonably uniform in slope and soil type. These subcatchments should also be in the same management practice. Each subscatchment should have well defined hydrologic boundaries and water outlets. Soil moisture measurements will consist of soil water content determinations using the double gamma-ray attenuation technique and gravimetric measurements where and when necessary. Concurrently with these measurements, determinations will be made of soil water potentials using any or all of the following measuring devices: matrix potential sensors, tensiometer, resistance blocks, and thermocouple psychrometers. Field data will be supplemented with laboratory determinations of the hydraulic conductivity and soil water characteristics.

Soil moisture measurements will be concentrated in randomly selected "stations" within a subcatchment. A minimum of 3 stations, but preferably 5 stations, per subcatchment will be chosen. Each station will have at least 1 set of dual-access tubes for soil moisture content measurements using the double gamma-ray attenuation technique. An assorted array of soil moisture potential measurements may be placed at various locations within each station and at regularly spaced intervals in the soil profiles. The number and type of sensors will depend on local soil (homogenous or heterogeneous) and groundwater levels. However, an ample number of sensors of a given type will be placed to determine the local variability in the soil moisture state as well as the variability within each subcatchment. Piezometers will be placed where warranted by the groundwater regime. Output signals from sensors will be relayed to data loggers for subsequent analysis. Observations will be made at least once per day. However, gamma-ray attenuation measurements will be conducted at a lesser frequency depending on the workload of available personnel and time requirement for each scan and number of replications within each location.

Data will be analyzed to determine average water fluxes at various points within the soil profile and changes in the soil water balance in the overall soil profile. These measurements will be especially helpful in estimating that fraction of precipitation which enters the soil profile during and immediately following a rainstorm event. Also, losses to groundwater and evapotranspiration can thus be estimated.

Table 1. Schedule of Project Activities

Months since Project Approval

6 12 18 24 30 36 42 48

Phase I

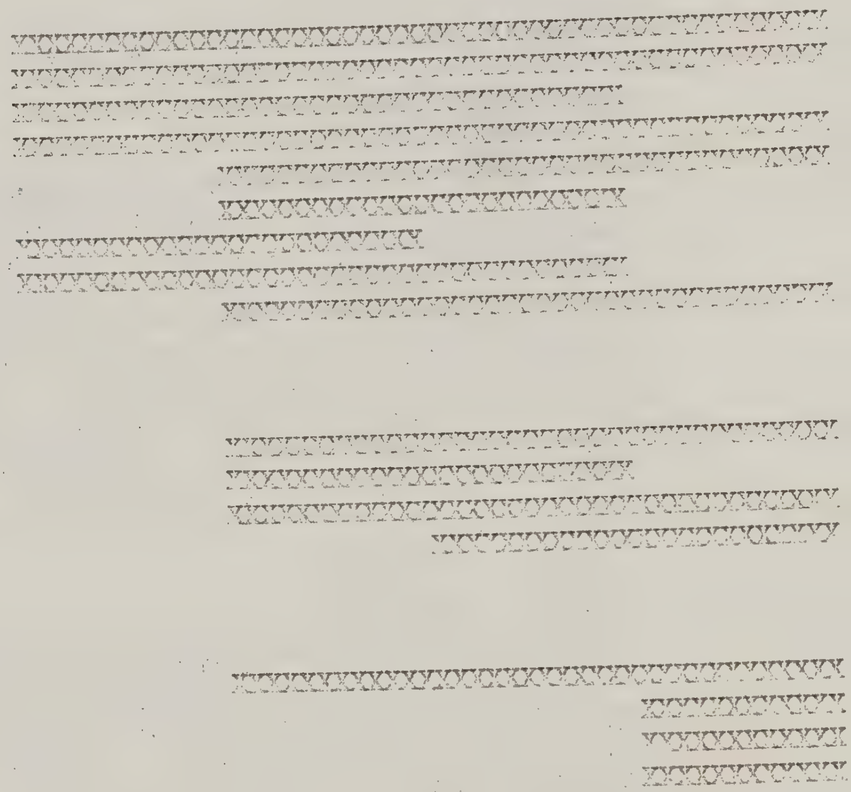
1. Planning
2. Literature Review
3. Design Field Stations
4. Equipment Purchases
5. Data Collection (field)
6. Soil Analysis
7. Personnel Recruitment
8. Calibration Equipment
9. Project Reports

Phase II

10. Operate Stations
11. Lab Analysis
12. Data Evaluation
13. Model Development

Phase III

14. Publish Results
15. Model Evaluation
16. Data Summary
17. Final Report



X = one month

3.1 Project Proposal Budget Summary

		Year I CE	Year I ABS	Year II CE	Year II ABS	Year III CE	Year III ABS	Year IV CE	Year IV ABS
4.1	Salaries								
	Professional								
	Project Manager								
	Principal Investigator		13,400				14,700		
	Associate Investigator	3,000				17,000			
	Other Personnel								
	Technician								
	Labor								
	Secretary								
	Graduate Student					6,500			
	Total Salaries	3,000	13,400			23,500	14,700		
4.2	Staff Benefits	450	1,300			3,500	1,500		
4.3	Total Salaries plus Benefits	3,450	14,700			27,000	16,200		
4.4	Equipment	107,000	15,000						
4.5	Materials and Supplies	2,000				2,000			
4.6	Travel	1,000							
4.7	Publication & Similar Type Costs								
4.8	Computer Costs					2,000			
4.9	Miscellaneous Costs								
4.10	Total Costs Other than Salaries (4.4-4.9)	110,000	15,000			4,000			
4.11	Total Direct Costs (4.3 + 4.10)	113,450	29,700			31,000	16,200		
4.12	Sedimentation Laboratory Overhead	4,500	1,000			2,800	1,000		
4.13	Subcontract Overhead	1,000				8,100			
4.14	Subtotal	118,950	30,700			41,900	17,000		
4.15	ARS Overhead 18%	21,400	5,600			7,500	3,100		
4.16	Total	140,350	36,300			49,400	20,100		